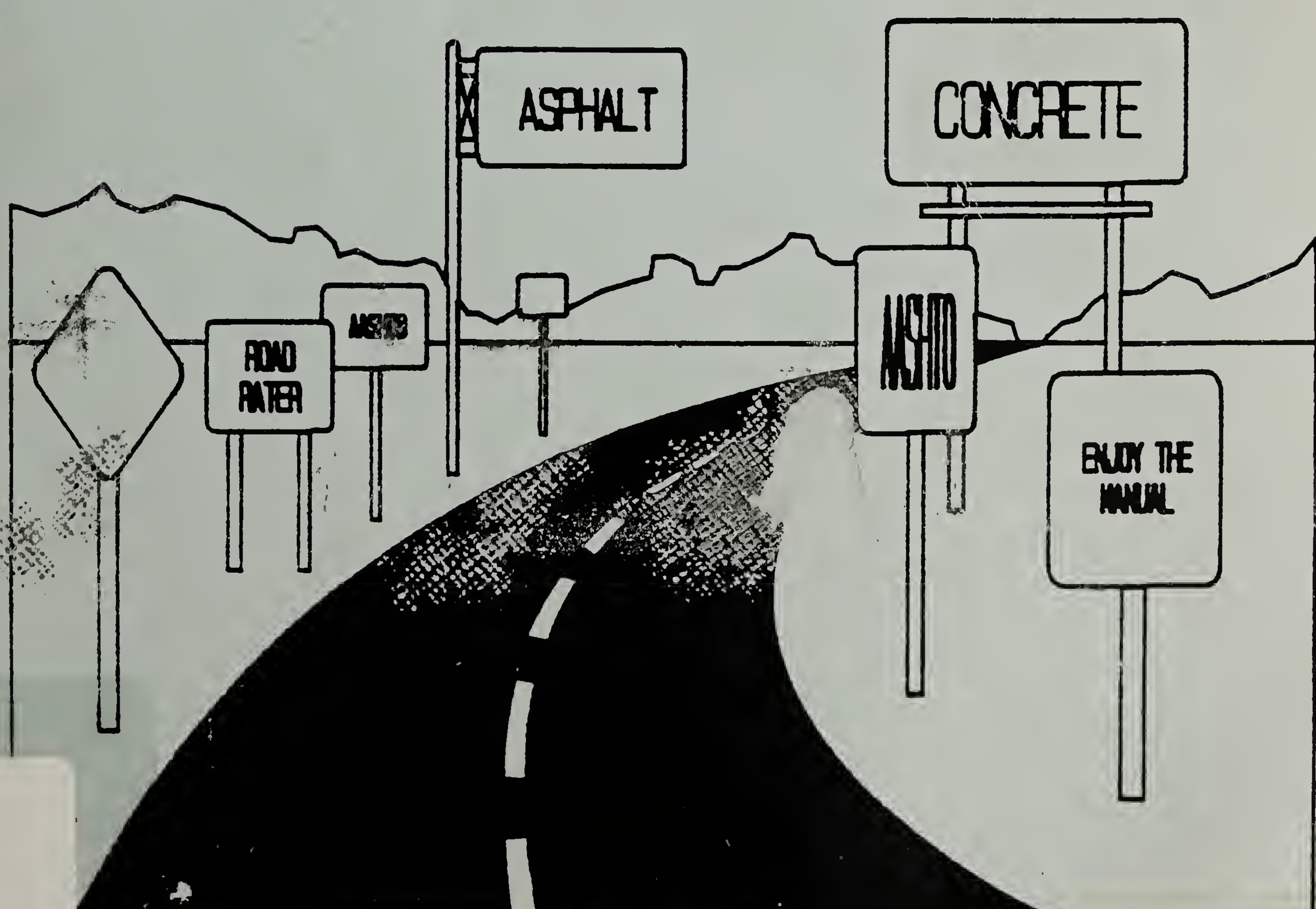
MONTANA DEPARTMENT OF TRANSPORTATION

PAVEMENT DESIGN MANUAL
1991



PREFACE

Contained within the following are the present Pavement Design Procedures for the Montana Department of Transportation. These procedures utilize the 1972 AASHTO Programs, Non-Destructive (Road Rater) Analysis and the 1986 New AASHTO Design Procedures (Rigid Pavements).

The Department of Transportation is currently in the process of implementing and revising these design procedures which include the 1986 New AASHTO Design Programs for Flexible Pavements and the use of mechanistic design, (Michpave Program). As areas of these current design procedures become outdated, amendment revisions will be sent out.

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1 PAVEMENT DESIGN PROCESS

This manual on Pavement Design is based on the 1972 AASHTO *Interim Guide* as revised in 1981. Since then, research has continued into the cost-effective design of highway pavements, resulting in the publication of the 1986 AASHTO *Guide for Design of Pavement Structures*. There are a number of new design procedure features included in this publication.

While these new design concepts appear very promising, the foundation needed to adopt them is not in place at this time. Until these new methods can be phased in, the Department will continue to design pavements based on a modification of the *Interim Guide*, which has provided satisfactory pavement structures since its introduction. We will also use Road Rater deflection analysis information for the design of overlay projects.

Effective pavement design is one of the more important aspects of project design. The pavement is the portion of the highway which is most obvious to the motorist. The condition and adequacy of the highway is often judged by the smoothness or roughness of the pavement. From a project design perspective, pavement and related items comprise from 10 percent to 90 percent of highway construction costs. Among the costs associated with underdesigned pavements are:

1. increased user costs (fuel consumption, tires, repair, etc.)

2. increased accident costs;

3. increased maintenance costs;

4. costs of user delays due to reconstruction and maintenance;

5. cost of early reconstruction.

Because pavement life is substantially affected by the number of heavy load repetitions applied and the deflections created by those loads, a poorly designed pavement will generally not be evident until years after construction. To design a pavement structure properly, the designer must rely on his/her own expertise as well as that of materials, traffic, soils and planning engineers. Considerations include:

1. *Evaluate existing pavement* to determine appropriate rehabilitation strategy, salvage value of existing materials or structure for new pavement. Determine the reason for any pavement failure. Review performance history with maintenance forces for groundwater problems, and other background information.

2. *Evaluate* drainage characteristics and structural bearing capacity of the pavement structure. This can be done through the use of a non-destructive device (i.e. Road Rater).

3. *Perform structural calculations and deflection analysis.* After selecting the appropriate preliminary rehabilitation strategy, the traffic, soils, pavement deflections and pavement materials data must be used to calculate specific pavement layer requirements.

4. *Compare feasible alternatives* (new pavement, recycling, overlay, etc.) and select the most economically sound method for construction.

5. *Set specifications.* The pavement materials, construction methods, and finished project requirements must be both practical to attain and clearly defined. The pavement designer must ensure that the plans, standard specifications, supplemental specifications, and special provisions clearly and unambiguously define the requirements.

1.1 PAVEMENT TYPES

Montana uses pavement design methods based on the method shown in the AASHTO *Interim Guide for the Design of Pavement Structures* and deflection analysis and design based on Chevron analysis and DAMA programs. This manual outlines the design methods for flexible pavement (bituminous concrete) and rigid pavements (portland cement concrete). Rigid pavement design methods are presented in the 1986 AASHTO Guide "Thickness Design for Concrete Pavements."

In addition to the major pavement types (rigid and flexible), a combination of bituminous concrete over the portland cement concrete may be used. These are called composite pavements.

A flexible pavement can consist of four layers -- subgrade, subbase (foundation), base, and surface. The subbase can consist of a sand surfacing, special borrow, or select surfacing placed on the subgrade. The base course can consist of an untreated gravel base, cement or lime-treated, cement-treated base, or a bituminized base. The surface can

consist of Grade A, B, or C plant mix surfacing. There may or may not be a surface treatment applied.

A rigid pavement is portland cement concrete placed on a granular and/or stabilized base. In addition, it can be placed over an asphalt cement surfacing layer. Portland cement pavements are either plain jointed, jointed reinforced or continuously reinforced. However, currently Montana uses strictly plain jointed rigid pavements.

1.2 TRAFFIC

Highway traffic is typically a combination of many different types of vehicles having different gross weights and axle configurations. However, many design procedures require that these applied loads be converted into an equivalent number of applications of a standard axle load. The 18-kip equivalent single axle load (18-kip ESAL) is the standard used most widely by highway agencies.

The process of collecting mixed traffic data and converting it into 18-kip ESAL's is complex. Detailed traffic data must be gathered and analyzed to identify the types of vehicles using the facility and to estimate accurately their volumes (numbers) and weights. Past, current and potential traffic growth trends must be recognized to allow proper estimates of past traffic loads and reliable predictions of future loads. These load applications can then be converted to an equivalent number of applications of a standard design axle load using "equivalent damage" concepts.

The measurement and projection of traffic volumes and weights is subject to much variability and interpretation. However, it is important to do a good job of characterizing traffic in order to develop good rehabilitation and pavement design inputs. Small errors carried through the project

design life can produce unexpected results, such as extreme underdesign and premature failure or overdesign and unnecessary expense. Thus, this extremely difficult task is also extremely important and an effort must be made to remove as much speculation as possible from the traffic estimation process.

1.3 DEFINITIONS AND ABBREVIATIONS

Base Course - The layer or layers of specified or selected material of designed thickness placed on a subbase or a subgrade to support a surface course.

Composite Pavement - A pavement structure composed of an asphalt concrete wearing surface and portland cement concrete slab used as a base layer; an asphalt concrete overlay on a PCC slab is also referred to as a composite pavement.

Daily Equivalent 18-Kip Load - The average number of equivalent 18-kip loads which will be applied to the pavement structure in one day. Normally, a 20-year design period is used to determine the daily load. (See page 30.)

Equivalent Single-Axle Loads (ESALs) - The total number of standard axle load applications (converted from mixed traffic) summed over the design period or other portion of time.

Flexible Pavement - A pavement structure which maintains intimate contact with and distributes loads to the subgrade and depends on aggregate interlock, particle friction, and cohesion for stability.

Layer Coefficient - The relative structural value of each material type per inch of thickness. It is multiplied by

the layer thickness to provide the contributing SN for each pavement layer.

Load Equivalency Factor (LEF) - The number of applications of a standard axle (generally an 18,000-lb. single axle) required to produce the same damage or loss of serviceability as a single application of a different axle load and/or configuration used to convert mixed traffic to an equivalent number of applications of a standard axle.

Materials Engineer - ME

Materials Services Section Supervisor - MSSS

Pavement Analysis Supervisor - PAS

Resilient Modulus - is a means of evaluating pavement materials under given environmental and stress conditions to determine the resulting deformation. The MDT uses resilient modulus within its deflection analysis programs. They are backcalculated for each pavement layer from the Road Rater deflections.

Resistance Value (R-value) - The R-value is the ability of a given soil to resist lateral deformation under load. The better the roadbed, the less pavement material will be required to resist the deformation. R-values are determined as set forth in AASHTO T 190-78(86).

Rigid Pavement - A pavement structure which distributes loads to the subgrade, having as one course a portland cement concrete slab of relatively high-bending resistance.

Selected Material - A suitable native material obtained from a specified source such as a particular roadway cut or

borrow area, of a suitable material having specified characteristics to be used for a specific purpose.

Serviceability Index - A measure of a pavement's ability to serve high-speed, high volume automobile and truck traffic on a scale of 0 to 5 (5 being the best). The primary measure of serviceability is the present serviceability index (PSI). For Montana, PSI is a computed number containing roughness and rutting (flexible). This is an indication of the present ride quality of the highway. It reflects the extent of pavement distress.

Soil Support Value (SSV) - An index of the relative ability of a soil or stone to support the applied traffic loads. It is specifically used for the pavement design method in the AASHTO *Interim Guide for Design of Pavement Structures*. The soil support value of the subgrade is related to its R-value.

Structural Number (SN) - A measure of the structural strength of the pavement section based on the type and thickness of each layer within the pavement structure.

Subgrade - The top surface of a roadbed upon which the pavement structure and shoulders are constructed.

Surface Course - One or more layers of a pavement structure designed to accommodate the traffic load, the top layer of which resists skidding, traffic abrasion, and the disintegrating effects of climate. The top layer of flexible pavements is sometimes called "wearing course."

Subbase - The layer or layers of specified or selected material of design thickness placed on a subgrade to support a base course (or in the case of rigid pavements, the portland cement concrete slab).

Terminal Serviceability Index (Pt) - A pavement design factor which is based on the lowest index that will be tolerated before rehabilitation, resurfacing or reconstruction becomes necessary. An index of 2.5 is recommended for major routes and 2.0 for lesser highways by AASHTO. The Department designs for a terminal serviceability (Pt) equal to 2.5 for interstates and primaries and 2.0 for secondaries.

2 PROCEDURES

Section 1 describes the MDT pavement design process. The design process is put into motion after a request by the Area Engineer for his particular district. These are Activities 600 and 610 in the Preconstruction Management System. All pavement designs are determined by the Pavement Analysis Section with the MDT Materials Engineer reviewing and approving all pavement designs. The major activities in the design process are:

ACTIVITY 1 PAS REVIEWS AVAILABLE PROJECT DATA

Prior to the preprogram review, the Pavement Analysis Supervisor will review the available project data and if possible, the Pavement Design Supervisor will develop a rough estimated design.

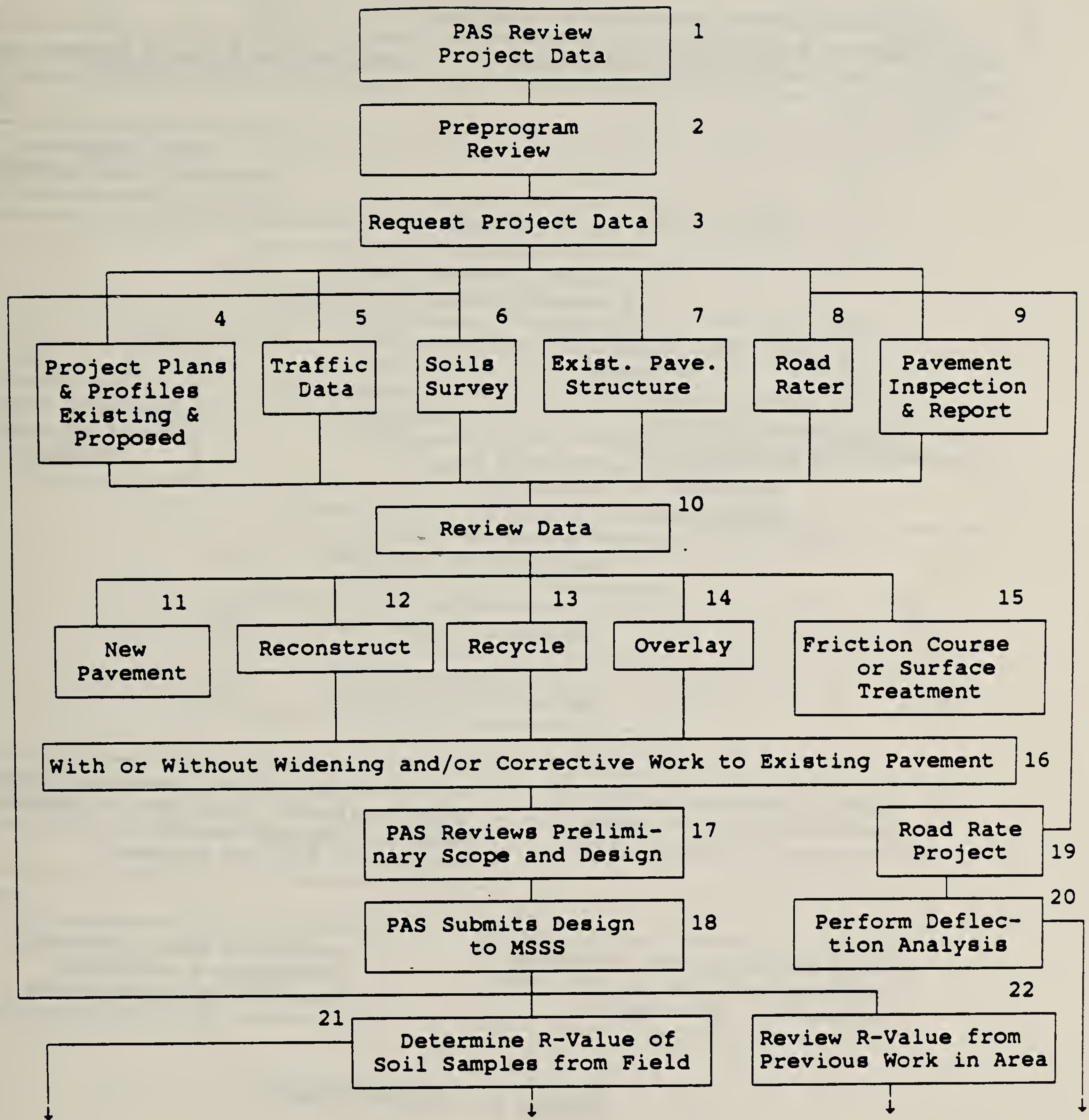


Figure 2.1 PAVEMENT DESIGN PROCESS

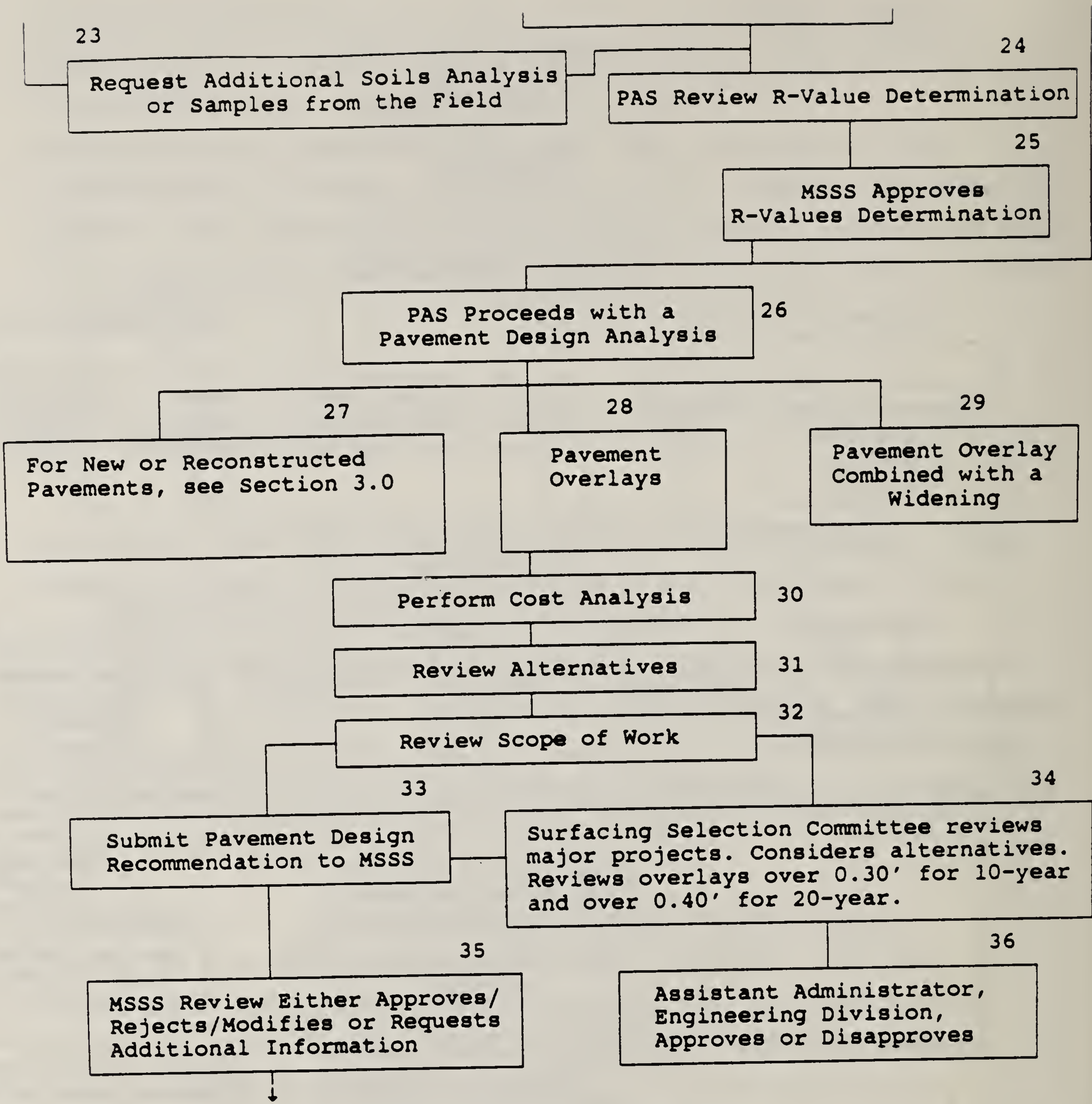


Figure 2.1 (Continued)

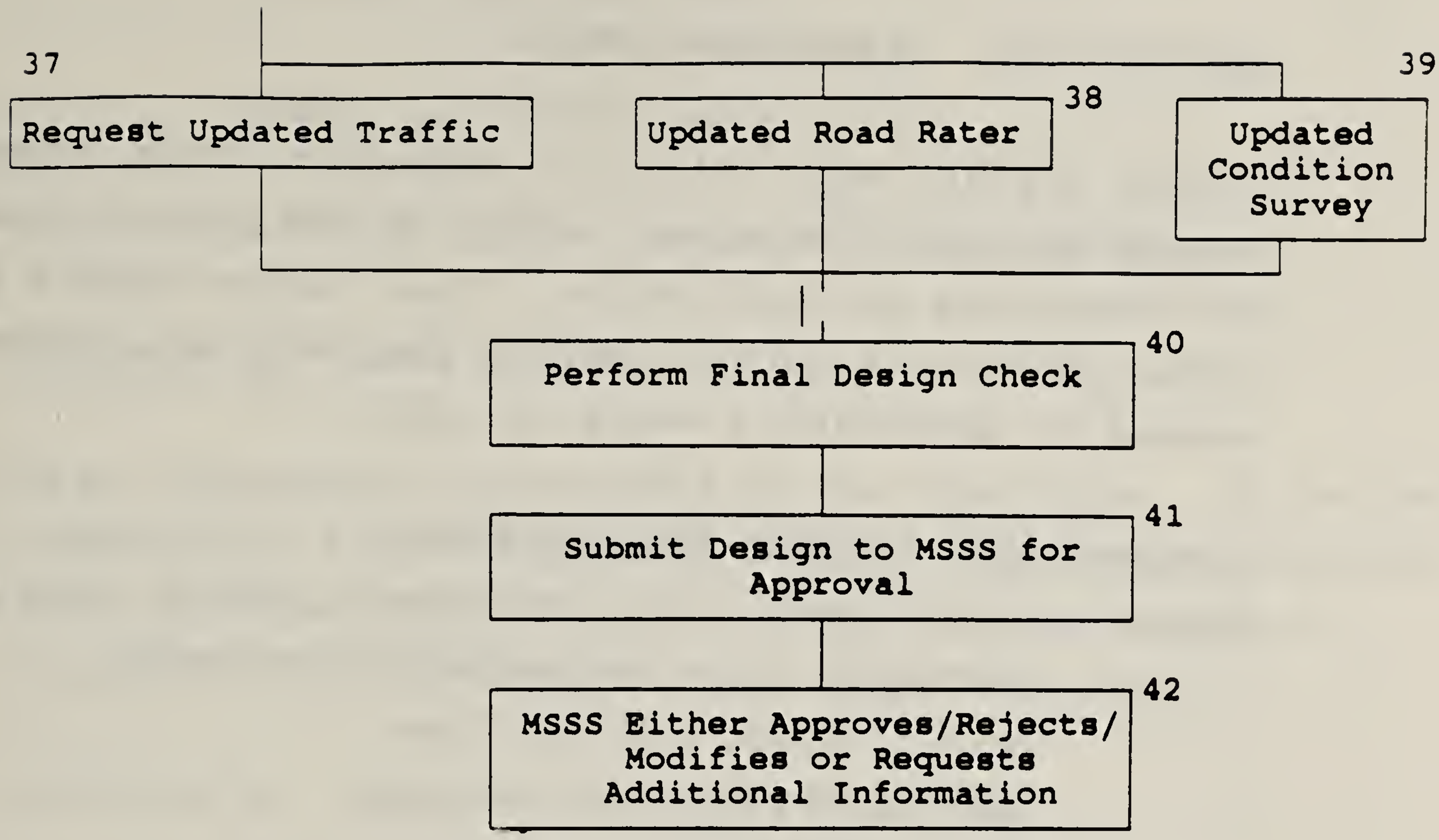


Figure 2.1 (Continued)

ACTIVITY 02 PREPROGRAM REVIEW

Either the ME, MSSS, PAS will attend or offer comments prior to the review. The actual scope of the project should not be determined at this review. This review should instead offer possible alternatives and the various information needed to determine a scope of work.

ACTIVITY 03 REQUEST PROJECT DATA

Either at or following the preprogram review, the following information needs to be requested or gathered.

1. Project plans and profiles
2. Traffic data
3. Soils survey
4. Existing pavement structure thicknesses
5. Road Rater deflection analysis and design
6. Pavement condition report

ACTIVITY 04 PROJECT PLANS AND PROFILES (Existing & Proposed)

These shall be submitted to the Pavement Analysis Supervisor.

ACTIVITY 05 TRAFFIC DATA

The traffic data includes the following and shall be submitted to the Pavement Analysis Supervisor.

1. Current ADT and ESALs (for year of proposed rehabilitation)

2. Projected ADT and ESALs (20 years)

3. ADT truck percentage

4. Number of lanes with directional factor, if applicabl

5. Divided/undivided, and

6. Source of traffic data

Enter these data on the pavement design worksheet.

ACTIVITY 06 SOIL SURVEY

This information is provided by the Districts. It can be information from recent soil R-value samples or from past soil surveys. However, it must be complete enough to represent the existing pavement structure.

ACTIVITY 07 EXISTING PAVEMENT STRUCTURE

The thickness and type of each pavement layer (i.e., surface, binder, base and subbase) shall be recorded; it is especially necessary for overlay and recycling projects.

ACTIVITY 08 ROAD RATER

Road Rater deflection analysis and design information will primarily be used for overlay designs. This information will be used to develop the complete design package.

ACTIVITY 09 FIELD INSPECTION REPORT

The report (pages 24-28) shall include the general condition and distress extent of the roadway such as cracking (type, amount) rutting, rideability, and any other characteristic that may be pertinent to the selection of pavement type and scope of work. This report will be filled out by road rater personnel during testing. In addition, it is recommended one be filled out at the Preprogram field review by the Area Engineer and/or district.

ACTIVITY 10 REVIEW PROJECT DATA

After requesting the various project data, the PAS will review the data and the design options with the Design Supervisors.

ACTIVITY 11 NEW PAVEMENT

A new pavement is a pavement structure which is placed on a previously undisturbed subgrade. It applies to a highway on new location, to a relocated highway, or to the new part of a widened highway.

ACTIVITY 12 RECONSTRUCTED PAVEMENT

A reconstructed pavement is one which results when an existing pavement structure is completely removed to the subgrade and replaced with a new pavement structure. This type of work is needed when the existing pavement has deteriorated to such a weakened condition that it cannot be salvaged with corrective action. The type and extent of pavement distress will determine when pavement reconstruction is necessary.

ACTIVITY 13 RECYCLED PAVEMENT

A recycled pavement results when an existing pavement structure (from which all or part of the pavement is removed on or off site), is combined with new materials and replaced. Recycling is performed in conjunction with a pavement overlay or reconstructed pavement. All proposed recycling projects must be economically justified.

ACTIVITY 14 PAVEMENT OVERLAY

A pavement overlay consists of placing the needed thickness of bituminous concrete on an existing pavement. The overlay will return the pavement to a high level of serviceability and provide the necessary structural strength for the pavement design period.

ACTIVITY 15 FRICTION OR SURFACE TREATMENT

A pavement may not require any corrective work other than the application of a friction course because of low skid resistance. In some instances, a friction course or a seal and cover may be placed on new or reconstructed pavements. The friction course does not add to the structural integrity of the pavement as it is 3/4" thick.

ACTIVITY 16 WITH/WITHOUT WIDENING &/OR CORRECTIVE WORK TO THE EXISTING PAVEMENT

A) A pavement may be reconstructed without any additional work or the reconstruction may include widening, shoulders, extra lanes, etc. in addition to the new pavement structure.

B) A recycling project may consist simply of improving the pavement structure by one of the many methods of recycling. Other recycling projects may include the addition of shoulders, widening, etc. The type of work required is to be considered when selecting the methods or type of recycling.

C) An overlay may be placed on the existing surface without any other work except that related to the overlay. An overall pavement rehabilitation project (widening, additional lanes, improved geometry, etc.) usually includes an overlay. In many cases, a

certain amount of corrective work may be required prior to the placing of an overlay. This work may consist of strengthening weakened subgrade where indicated, removing and replacing badly deteriorated surface areas, placing a leveling course, filling ruts and depressions. Include also any operations that will minimize reflective cracking.

ACTIVITY 17 REVIEW THE PRELIMINARY DESIGN SCOPE OF WORK

The PAS and Pavement Design Supervisor will review the preliminary design and scope of work for the pavement design. This can be a new pavement, reconstructed pavement, pavement overlay, or a combination of any two. (The design should document the reasons for the decision.)

ACTIVITY 18 PAS SUBMITS PRELIMINARY DESIGN TO MSSS

The Pavement Analysis Supervisor after reviewing the preliminary design and scope of work will submit it to the MSSS for his review and comments.

ACTIVITY 19 ROAD RATER PROJECT

Each overlay project will be Road Rated at least one time prior to performing the pavement design. It will be the intention of the unit to try and test each project once prior to preprogram review and prior to completion of Activity 33 (PMS Activity 600). See Section 5.3 for specific testing details.

ACTIVITY 20 PERFORM DEFLECTION ANALYSIS AND DESIGN

After each project has been tested with the Road Rater, a pavement deflection analysis and design will be performed by the Road Rater area. Road Rater design results will not be distributed unless requested. What part will the Road Rater design results play in the overall design? Road Rater and the AASHTO designs will be used in conjunction for the total

overlay design package. In addition to both design methods, present pavement distress and past performance will be used. Since both design methods are totally different in nature, differences in the designs will occur. In those cases after checking both designs, pavement condition and performance will dictate which method the design <u>may</u> favor. This will be done based on experience and engineering judgment.

Please refer to Section 5.3 for a review of the deflection analysis and design procedure and requirements.

ACTIVITY 21 DETERMINE R-VALUES

Section 3 and Data Sheet 2 discuss the procedure for determining the course of action for selecting an R-value.

ACTIVITY 22 REVIEW R-VALUE FROM PREVIOUS WORK

If it is available and still applicable, the pavement design engineer will review the R-value used for the original pavement design or any previous pavement overlays.

ACTIVITY 23 REQUEST ADDITIONAL SOILS ANALYSIS OR SAMPLES FROM THE DISTRICT (if needed)

If the pavement design engineer has recommended additional samples to determine the R-value and the PAS has concurred, the PAS will submit a request to the district.

1. Materials suggests an additional number of test holes and their locations. This information is shown on the project plans and forwarded to the district.

2. The district makes arrangements for sampling.

3. Normally, the district is responsible for test hole excavations on state and interstate highways. Under certain conditions, however, it may be more expeditious to have a consultant or the Materials Geology crew do the sampling.

4. Sampling will be in accordance with MT 207.

5. The Materials Bureau will determine the R-value. The report will be sent to the PAS.

ACTIVITY 24 PAS REVIEWS R-VALUE DETERMINATION

The PAS will review the pavement designer's determination of the subgrade R-value. If necessary, he will submit a request to the district for additional soils information or samples. (Activity 23)

ACTIVITY 25 MSSS APPROVES R-VALUES DETERMINATION

The MSSS reviews the Soil Survey and R-Values submitted. If they are representative of the project, the MSSS will approve the R-value submitted.

ACTIVITY 26 PAVEMENT ANALYSIS UNIT CONDUCTS PAVEMENT DESIGN ANALYSIS

Pavement Designer will conduct the detailed analysis to determine the type and thickness of each layer in the pavement structures. This will be reviewed by the PAS.

ACTIVITY 27 NEW/RECONSTRUCTED PAVEMENTS

On new and reconstructed pavements, the pavement designer will determine the detailed full-depth design of the pavement. The detailed procedure is discussed in Section 3. Recycling may be considered.

ACTIVITY 28 PAVEMENT OVERLAYS

On pavement overlays, the pavement designer will specify the depth of the bituminous concrete overlay. The detailed procedure is discussed in Section 4. In addition, the pavement designer will determine and recommend the corrective work needed on the existing pavement.

ACTIVITY 29 COMBINATION (PAVEMENT OVERLAY WITH WIDENING)

This type of work will require a combination analysis. Section 3 will determine the full-depth design of the widened section. Section 4 will determine the needed depth of overlay.

ACTIVITY 30 PERFORM COST ANALYSIS

During the design phase, each design will have a cost analysis performed concurrently with the design.

ACTIVITY 31 REVIEW ALTERNATIVES

The design supervisor will submit the list of design alternatives and cost analysis for each to the PAS for his review of the design recommendation.

ACTIVITY 32 REVIEW SCOPE OF WORK

The PAS and MSSS will review the scope of work after a design recommendation has been determined. If the recommendation differs from the scope, a memo shall be

submitted to the Surfacing Selection Committee for their review.

ACTIVITY 33 SUBMIT PAVEMENT DESIGN RECOMMENDATIONS TO MSSS

The PAS will submit the recommended detailed pavement design with completed data sheets to the Materials Services Section Supervisor for his approval.

ACTIVITY 34 SURFACING SELECTION COMMITTEE

This committee reviews major projects and considers alternative surfacing sections. They also review overlays thicker than 0.30′ for a 10-year design and overlays thicker than 0.40′ for a 20-year design (see page 69).

ACTIVITY 35 MSSS REVIEWS AND APPROVES/DISAPPROVES/MODIFIES/ REQUESTS ADDITIONAL INFORMATION

The Materials Services Section Supervisor will review the pavement design recommendation from the Pavement Analysis Unit and will approve, disapprove, modify, or request additional information from the design engineer. The Materials Services Section Supervisor will notify the PAS of the action taken.

ACTIVITY 36 APPROVAL/DISAPPROVAL

The Assistant Administrator of the Engineering Division will review the ME and/or the committee's findings and approve or disapprove its decision.

ACTIVITY 37 REQUEST UPDATED TRAFFIC

The PAS will request for updated traffic prior to the final plan-in-hand.

ACTIVITY 38 REVIEW UPDATED ROAD RATER DATA

Prior to final design check, the Road Rater will provide or try to provide a second analysis.

ACTIVITY 39 REVIEW UPDATED CONDITION SURVEY

Prior to the final design check, the pavement design engineer will review Pavement Management System, Road Rater observations and other condition surveys.

ACTIVITY 40 PERFORM FINAL DESIGN CHECK

The pavement analysis supervisor will perform a final design check prior to the final plan-in-hand.

ACTIVITY 41 SUBMIT DESIGN FOR FINAL APPROVAL

The Materials Services Section Supervisor will review the final pavement design recommendation from the Pavement Analysis Unit and will approve, disapprove, modify or request additional information from the design engineer. The MSSS will notify PAS of action taken.

ACTIVITY 42 MSSS APPROVES/REJECTS

The Assistant Administrator of the Engineering Division will review the ME and/or committee's findings and approve or disapprove its decision.

PAVEMENT INSPECTION REPORT (Activity 9)

Project Rater ____________________
Date ____________________

I. Project Identification

Project Number ____________________
From MP ____________________
Lane ____________________

Project Termini ____________________
To MP ____________________

II. Traffic Data

Current ADT (Year) ____________________
Current ADL ____________________

Future ADT (Year)* ____________________
Design ADL ____________________

FLEXIBLE PAVEMENT CONDITION RATING FORM

DISTRESS	Ave. Feet/500'	Distress Weight	Severity Weight * L	M	H	Extent Weight ** O	F	E	Deduct Points***
Raveling		10	.3	.6	1.0	.5	.8	1.0	
Bleeding		10	.8	.8	1.0	.6	.9	1.0	
Patching		5	.3	.6	1.0	.6	.8	1.0	
• Potholes		10	.4	.7	1.0	.5	.8	1.0	
• Rutting		15	.3	.7	1.0	.6	.8	1.0	
•Alligator Cracking		20	.4	.7	1.0	.5	.7	1.0	
Transverse Cracking		10	.4	.7	1.0	.5	.7	1.0	
Longitudinal Cracking		10	.4	.7	1.0	.5	.7	1.0	
Block Cracking		10	.4	.7	1.0	.5	.7	1.0	

Total Deduct =
Sum of Structural Deduct =
100 - Total Deduct = **PCR** =

* L = Low
M = Medium
H = High

** O = Occasional
F = Frequent
E = Extensive

• - Indicates structural distress
*** Deduct pts. = Distress Wt. x Severity Wt. x Extent Wt.

Remarks:

III. Existing Pavement Information

Year Initially Constructed ________ Overlaid ______________

Existing Pavement Structure:

Layer	DepthType
Surface	____________________
	____________________
Base	____________________
	____________________
Subbase	____________________

V. Proposed Corrective Work to Existing Pavement (if any)

[] Leveling Course[] Subdrainage Pipes
[] Crackfilling[] Deep Patching/Pothole Filling
[] Prime [] Other ____________________
[] Cold Planing[] Other ____________________
[] Heater/Scarifier[] Other ____________________

Discussion (if needed): ____________________
____
____
____
____

VI. Proposed Scope of Work

[] New Pavement[] Pavement Overlay
[] Reconstructed Pavement[] With Widening
[] Recycling[] Without Widening
[] Surface (in-place)[] With corrective work to existing
[] Cold-Mix pavement
[] Hot-Mix [] Without corrective work to existing
pavement
[] Other

Discussion (if needed): ____________________
____
____
____
____

VII. Briefly discuss reasons for proposed work, including estimated costs and any special site conditions which may limit the practical choices.

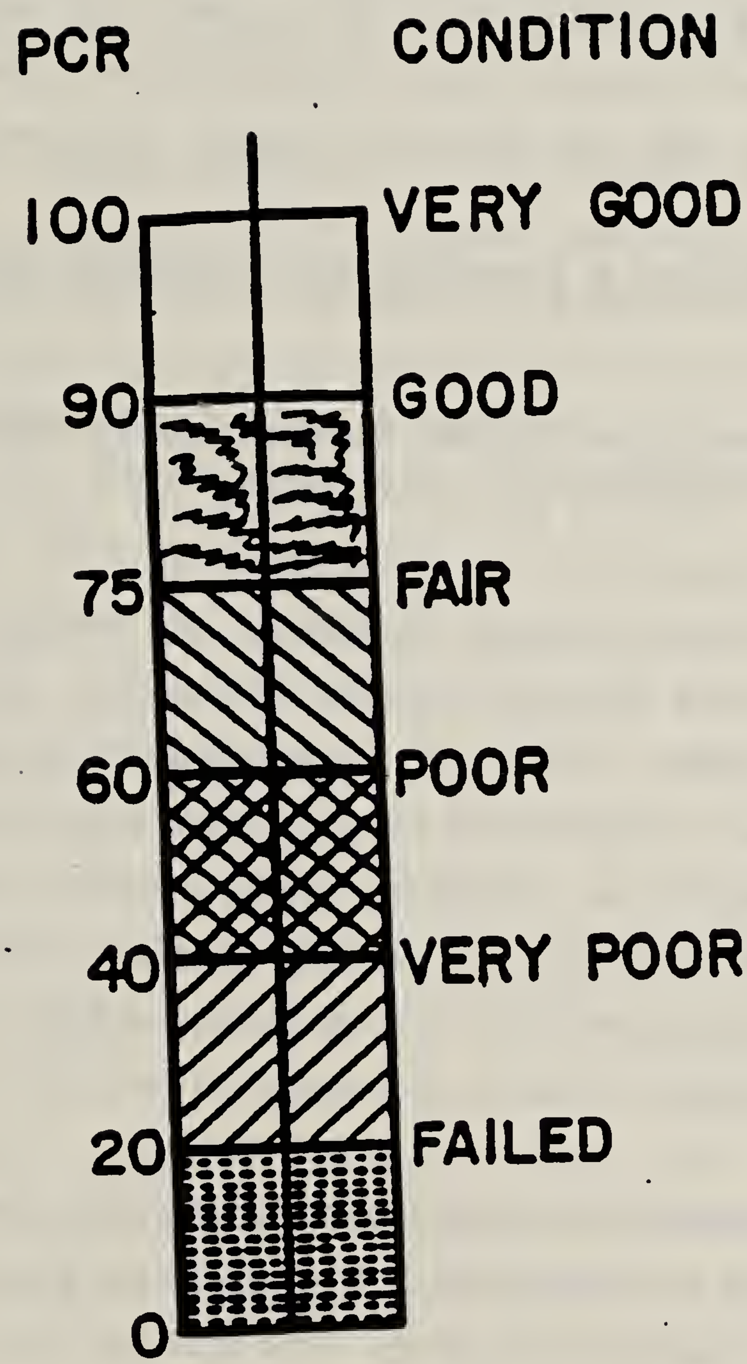
____
____
____
____
____
____

KEY
FLEXIBLE PAVEMENT CONDITION RATING FORM

DISTRESS	Distress Weight	Severity Weight *			Extent Weight **		
		L	M	H	O	F	E
Raveling	10	Some coarse loss	Open texture	Rough or pitted	<20%	20-50%	>50%
Bleeding	10	Aggregate visible	Aggregate visible	Black surface needs	<10%	10-30%	>30%
Patching (deterioration)	5	Slight	Moderate	Needs replaced	<10%	10-30%	>30%
Potholes	10	1 in. deep	1-2 in. deep	>2 in. deep	<20%	20-30%	>30%
Rutting	15	<1/4-1/2 in.	1/2 - ¾ in.	>¾ in.	<20%	20-50%	>50%
Alligator Cracking	20	Single <1/8 in.	Multiple >1/8 in.	Alligator >1/4 in.	<20%	20-50%	>50%
Transverse Cracks	10	<1/8 in.	1/8 - 1 in.	>1 in.	<20%	20-50%	>50%
Longitudinal Cracks	10	Single <1/8 in.	Multiple >1/8 in.	Multiple spall	<20%	20-50%	>50%
Block Crack	10	<1/8 in.	1/8 - 1 in.	<1 in.	<20%	20-50%	>50%

*L = Low M = Medium H = High

** O = Occasional F = Frequent E = Extensive


PCR
CONDITION
100
VERY GOOD
90
GOOD
75
FAIR
60
POOR
40
VERY POOR
20
FAILED
0

3.0 NEW AND RECONSTRUCTED PAVEMENTS (FLEXIBLE)

MDT uses the AASHTO *Interim Guide for Design of Pavement Structures* for its design of flexible pavements. However, MDT has incorporated several modifications to the *Guide's* procedures to reflect specific conditions in Montana and to simplify the procedure. This section specifies the MDT procedure and inputs for determining the flexible pavement design of a new or reconstructed pavement.

3.1 FLEXIBLE PAVEMENT DESIGN INPUTS

1) **TRAFFIC - DAILY 18-KIP EQUIVALENT AXLE LOAD COMPUTATIONS (see Data Sheet 1)**

This information is provided by the Traffic Section of the Preconstruction Bureau. As noted on the data sheet, the average daily 18-Kip ESALs for a 20-year design life is computed. If any other design period is requested, the total number of 18-Kip for the design period is used. For example, a 10-year design would require that the total 18-Kip EAL be (daily ESAL x 10 x 365). When you enter the nomograph, the total ESALs would be used. (Data Sheet 3 or 4 - pages 33 and 34).

2) **DESIGN R-VALUE DETERMINATION (see Data Sheet 2)**

R-Values are provided by the Materials Bureau on soil samples submitted from the field soil survey. R-Value samples are reviewed as to location of sample and soil class. The R-Values are plotted on a graph to determine where the 85th percentile plots. This will usually be the R-Value at which the roadway is designed. The following are the steps in determining the 85th percentile:

Step #1: List all the representative R-Values under the R-Value column, beginning with the lowest.

Step #2: Under the Number => column, list the number of R-Values that are equal to or more than the corresponding R-Value to the left. For example; if R-Values ranged from 51 to 81 and there are 18 total R-Values, the first number is 18. If the second R-Value was 56 and there was only one, the number under 18 would be 17.

Step #3: Each number in the center column is divided by the total number of R-Values and multiplied by 100. These percentages are then plotted and connected with a line. Some interpolation may be necessary. A point where this line crosses 85 percent becomes the R-Value that is used in the surfacing design.

A work sample is shown on page 31 in this manual. In all instances, the soil survey should be reviewed to determine major changes in soils and R-values. For example, it may be very clear that for the first three miles of a seven-mile project, soils are fairly uniform and a particular R-value will represent the area. However, the remaining four miles may be substantially different and a different R-value may have to be used in the design. If this is the case, two typical sections may be recommended. Road Rater information should also be reviewed to determine changes in structural strengths.

3) **DETERMINING REQUIRED STRUCTURAL NUMBER (SN) (see Data Sheets 3 and 4)**

Step #1: Select the correct nomograph, either Data Sheet 3 or 4. Data Sheet 3 is used for interstate and primary. Data Sheet 4 is used for secondary and frontage roads.

Step #2: Plot the R-Value that was determined from soil survey samples and the 85th percentile. This is the line on left side of Data Sheets 3 and 4.

Step #3: Plot the Daily Equivalent 18-Kip single-axle load applications. Again, this is for a 20-year analysis period. This information is from Data Sheet 1.

Step #4: Connect these two points with a straightedge through the center line which gives a Structural Number.

Step #5: Draw a line from the Structural Number line in the center of the sheet through the Regional Factor, which has been plotted at 2.5. This factor is normally used in Montana. Carry the line through the vertical line on the right which is a weighted structural number. This is the structural number (SN) that is used in the design. This number must be satisfied to provide a 20-year design. To provide a typical that will have the required SN, a number of combinations of materials and thicknesses may be suggested. Economics and materials availability become a factor in making a final recommendation.

ADDITIONAL TABLES

Table 3-1 and Table 3-2 provide information for minimum design criteria. The tables are based on 20-year design.

Table 3-1 also has minimum and maximum thicknesses for Plant Mix Bituminized Surfacing to be placed in one lift. Table 3-2 lists coefficients for various surfacing types. Structural numbers are computed by multiplying

corresponding coefficients times the corresponding layer thickness.

Table 3-3 is estimating data used to determine planned quantities.

●●●●●●

DATA SHEET 1

Daily 18 KIP Equivalent Axle Load Computation

Project No:	F 20-1(4)1	Date:	26-Sep-88
Description:	Glendive - North	Pavement Type:	Rigid
			Flexible:X

Current AADT: 1680	Current AADT: 1990	Lane Design
Design AADT: 2050	Design AADT: 2010	Factor: 100%

Vehicle Type	% of Type	Current ADT	Design Year ADT	Mean Year ADT	Directional ADT	Design Lane ADT	18K Equiv Rate Fac	Mean Year ADL
Pass. Car		0	0.0	0.0	0.0	0.0		0.00
Pickup & Van		0	0.0	0.0	0.0	0.0		0.00
Busses		0	0.0	0.0	0.0	0.0		0.00
2 Axle/4 Tire		0	0.0	0.0	0.0	0.0		0.00
2 Axle/6 Tire	4.4	73.92	90.2	82.1	41.0	41.0	0.351	14.40
3 Axle S.U.	0.9	15.12	18.5	16.8	8.4	8.4	0.527	4.42
4 Axle or More S.U.		0	0.0	0.0	0.0	0.0		0.00
3 Axle Semi		0	0.0	0.0	0.0	0.0		0.00
4 Axle Semi	0.7	11.76	14.4	13.1	6.5	6.5	0.545	3.56
5 Axle Semi	5.9	99.12	121.0	110.0	55.0	55.0	1.504	82.75
6 Axle Semi	0.5	8.4	10.3	9.3	4.7	4.7	1.640	7.65
3 Axle Truck/Full Tr		0	0.0	0.0	0.0	0.0		0.00
4 Axle Truck/Full Tr		0	0.0	0.0	0.0	0.0		0.00
5 Axle Truck/Full Tr	0.2	3.36	4.1	3.7	1.9	1.9	2.102	3.92
6 Axle Truck/Full Tr	2.6	43.68	53.3	48.5	24.2	24.2	1.708	41.41
5 Axle Tr/Semi/Full	1.3	21.84	26.7	24.2	12.1	12.1	1.220	14.79
6 Axle Tr/Semi/Full		0	0.0	0.0	0.0	0.0		0.00
7 Axle Tr/Semi/Full	0.5	8.4	10.3	9.3	4.7	4.7	1.618	7.54
8 Axle Tr/Semi/Full	0.5	8.4	10.3	9.3	4.7	4.7	1.636	7.63
7 Axle Triple Tr.		0	0.0	0.0	0.0	0.0		0.00
8 Axle Triple Tr.		0	0.0	0.0	0.0	0.0		0.00
TOTAL VALUES	17.5							188.07

The Average Daily 18Kip EAL for a 20-year Design Life is 188.07

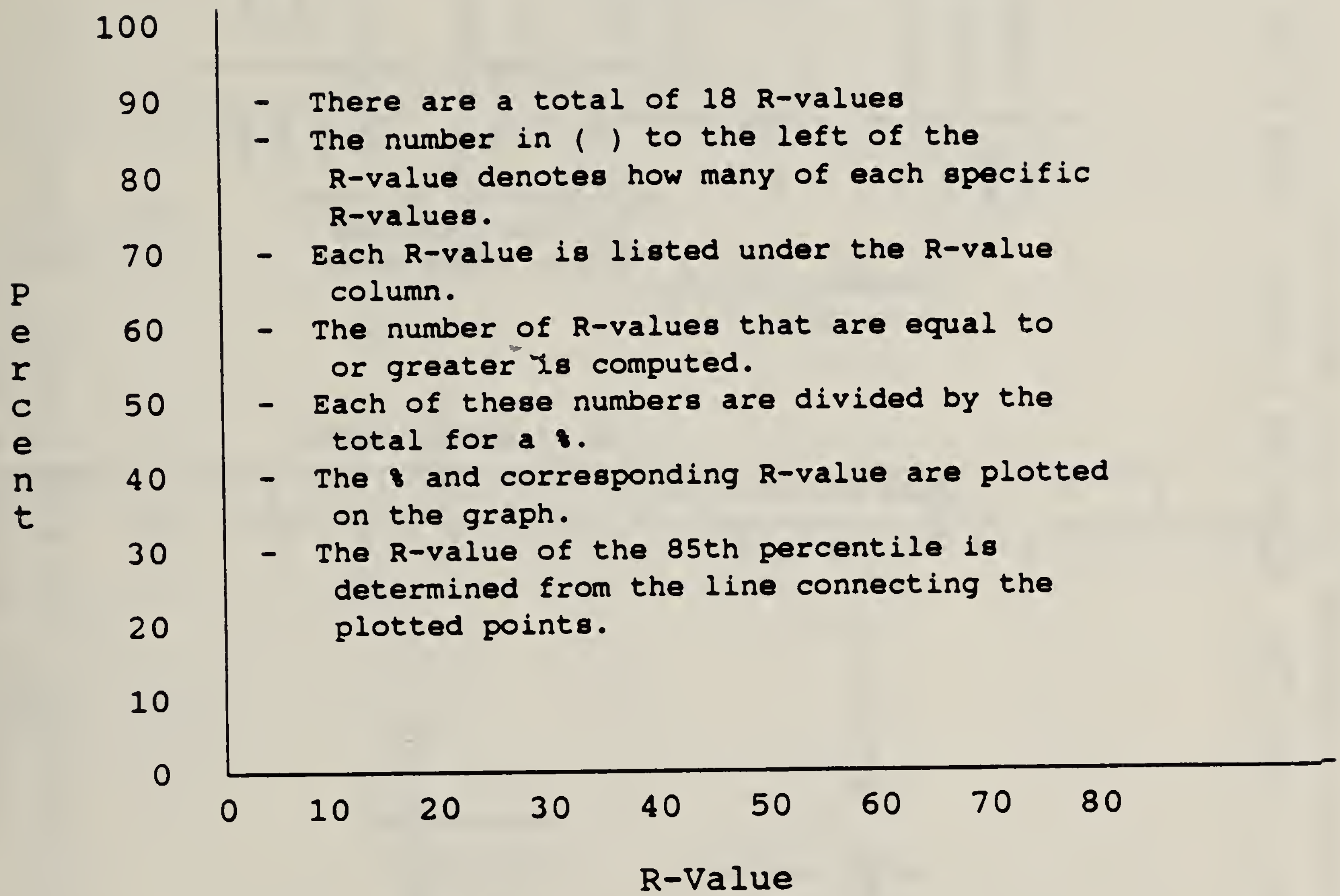
Design 18Kip Equivalent Axle Loads = 1,372.886

EXAMPLE DATA SHEET 2

STRENGTH VALUE

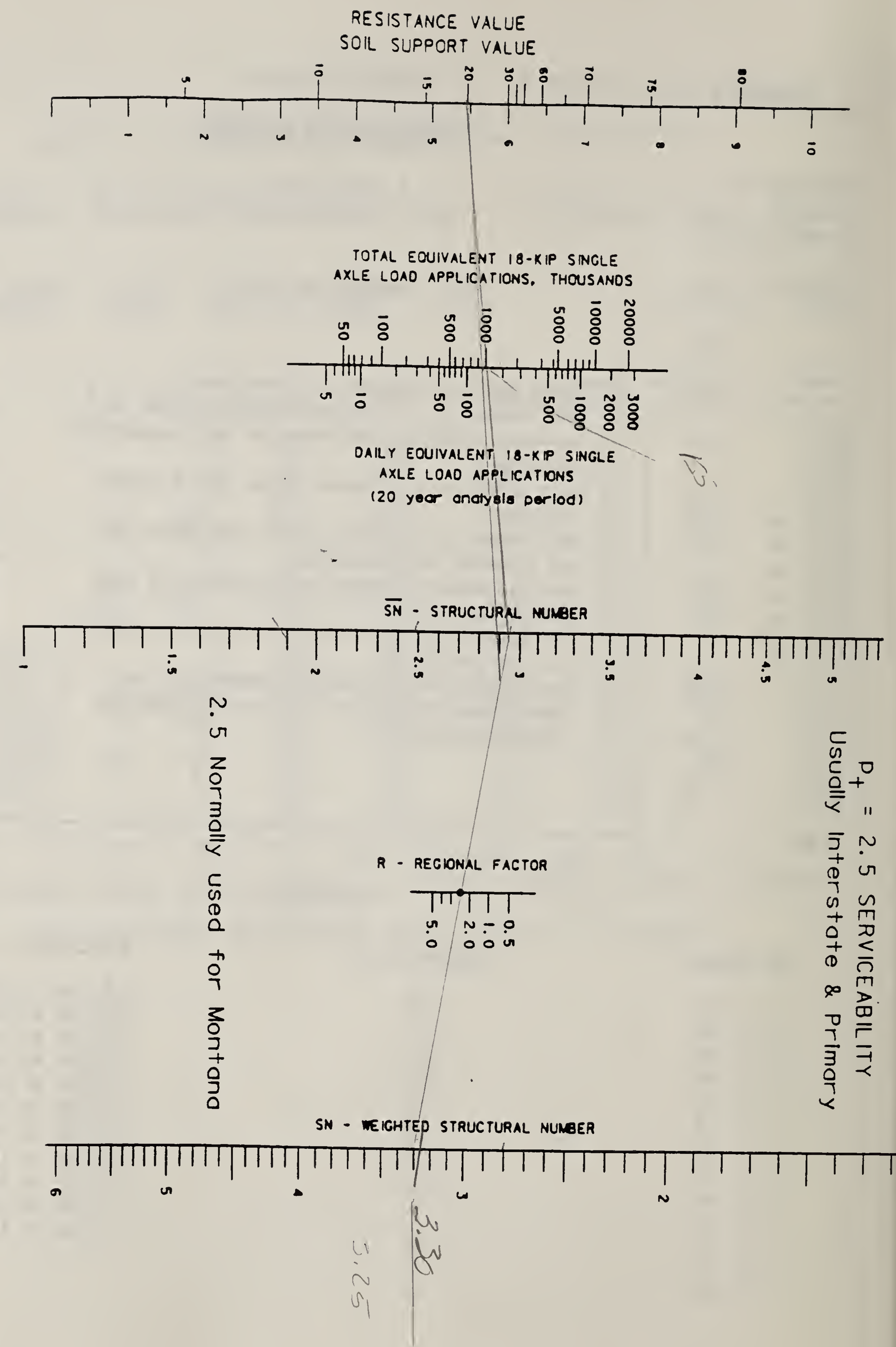
F 56-2(2)17
Bull Lake - North

Design R = 69



- There are a total of 18 R-values
- The number in ( ) to the left of the R-value denotes how many of each specific R-values.
- Each R-value is listed under the R-value column.
- The number of R-values that are equal to or greater is computed.
- Each of these numbers are divided by the total for a %.
- The % and corresponding R-value are plotted on the graph.
- The R-value of the 85th percentile is determined from the line connecting the plotted points.

R-Value	Number = >	% = to >
(1) 51	18	18/18 x 100 = 100
(1) 56	17	17/18 x 100 = 94
(1) 68	16	16/18 x 100 = 89
(1) 69	15	15/18 x 100 = 83
(1) 71	14	14/18 x 100 = 78
(1) 72	13	13/18 x 100 = 72
(1) 73	12	12/18 x 100 = 67
(1) 74	11	11/18 x 100 = 61
(3) 76	10	10/18 x 100 = 56
(3) 77	7	7/18 x 100 = 39
(2) 78	4	4/18 x 100 = 22
(1) 79	2	
(1) 81	1	



FLEXIBLE PAVEMENTS DESIGN CHART
20 YEAR TRAFFIC ANALYSIS

FLEXIBLE PAVEMENTS DESIGN CHART
20 YEAR TRAFFIC ANALYSIS

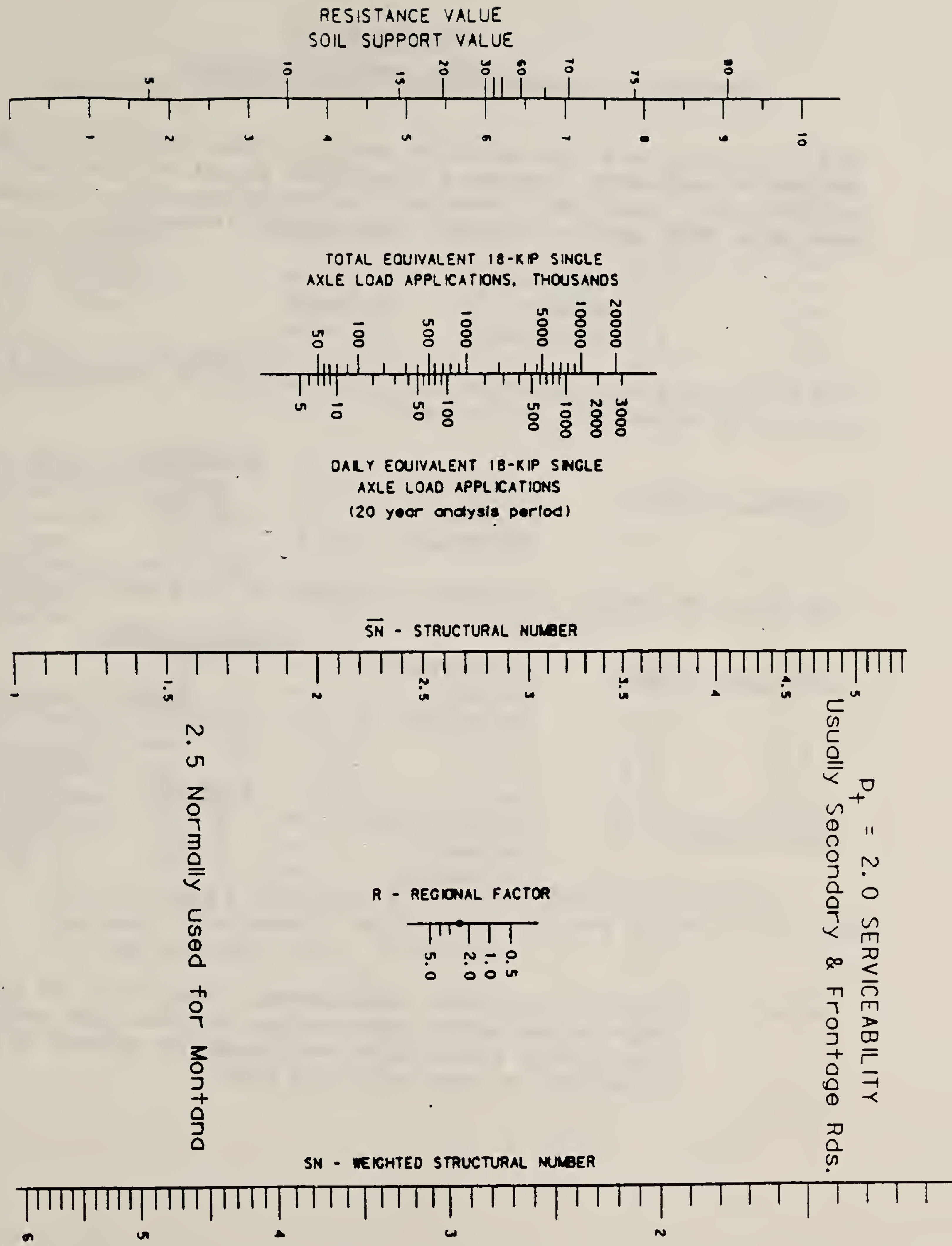


TABLE 3-1

MINIMUM DESIGN CRITERIA

The following are the minimum design lives for which the Pavement Analysis Unit will design. These are based on the FHWA PMS guidelines. However, it should be noted that the Pavement Analysis Unit will generally design for 20-years.

INTERSTATE	8 years
PRIMARY	8 years
SECONDARY	5 years

The following are the minimum thicknesses of the various types of surfacing materials to be used.

			ASPHALT	CONCRETE
SURFACE COURSE	INTERSTATE	=	0.40′	8"
	PRIMARY	=	0.30′	7"
	SECONDARY	=	0.30′	7"

The minimum design thickness of PMBS to be place is 0.15′.

			CRUSHED GRAVEL
LEVELING COURSE	INTERSTATE	=	0.20′
	PRIMARY	=	0.15′
	SECONDARY	=	0.15′

			ASPHALT	TREATED SOILS	CRUSHED GRAVEL
BASE COURSE	INTERSTATE	=	0.35′	0.35′	0.50′
	PRIMARY	=	0.35′	0.35′	0.50′
	SECONDARY	=	0.35′	0.35′	0.50′

Note: The only minimum requirements that will be placed on off-system bridge approaches is that the surfacing on the bridge approaches must meet or exceed the surfacing structure of the existing PTW.

.30

TABLE 3-2

SURFACING COEFFICIENTS FOR STRUCTURAL COMPONENTS

SURFACING COURSES	R-Value 70> Per Inch	R-Value 60-70 Per Inch	R-Value 70> Per Foot	R-Value 60-70 Per Foot
Plant Mix Grade A	0.33	0.30	4.0	3.6
Plant Mix Grade B	0.33	0.30	4.0	3.6
Plant Mix Grade C	0.31	0.28	3.7	3.4
Road Mix	0.20	0.18	2.4	2.2
Milled Asphaltic Material	0.16	0.14	1.9	1.7
Crushed Gravel	0.12	0.10	1.4	1.2
TREATED BASE COURSES				
Bituminous Stabilized	0.20	0.18	2.4	2.2
Cement Treated +400 psi at 7 Days	0.20	0.18	2.4	2.2
Cement Treated -400 psi at 7 Days	0.15	0.14	1.8	1.7
Lime Treated	0.15	0.14	1.8	1.7
GRAVEL BASE COURSES				
Crushed Gravel 1½" Max.	0.12	0.10	1.4	1.2
Crushed Gravel over 1½"	0.11	0.09	1.3	1.1
Selected Surfacing	0.10	0.08	1.2	1.0
Special Borrow	0.07	0.06	0.8	0.7
Sand Surfacing	0.05	0.05	0.6	0.6

NOTE: The R-Values referred to in the headings are the general R-Values of surfacing sources found in the area of the project being designed.

TABLE 3-3
ESTIMATING DATA

Plant Mix Bituminous Materials - 128.5# per tenth per s.y. + 5% contingency.

Asphalt Cement for Plant Mix Bituminous Material
- Grade A = 6.0% x weight of plant mix material
- Grade B = 6.0% x weight of plant mix material
- Grade C = 6.0% x weight of plant mix material

Asphalt Cement for Road Mix Bituminous Materials - 7% x weight of aggregate.
- Prime - 0.3 gal. of asphalt per s.y.
- Tack - 0.05 gal. of asphalt per s.y.
- Tack - O.G.F.C. - 0.05 gal. of asphalt per s.y.
- Tack - P.M.S.C. - 0.10 gal. of asphalt per s.y.
- Seal - 0.35 gal. of asphalt per s.y.

Aggregate for cover material = 25# per s.y.

Mineral Filler for Plant Mix - 1½% x weight of plant mix

Hydrated Lime for Plant Mix - 1½% x weight of plant mix

Aggregate Surfacing - 3700# compacted weight per c.y. or as recommended by the district + 5% contingency.

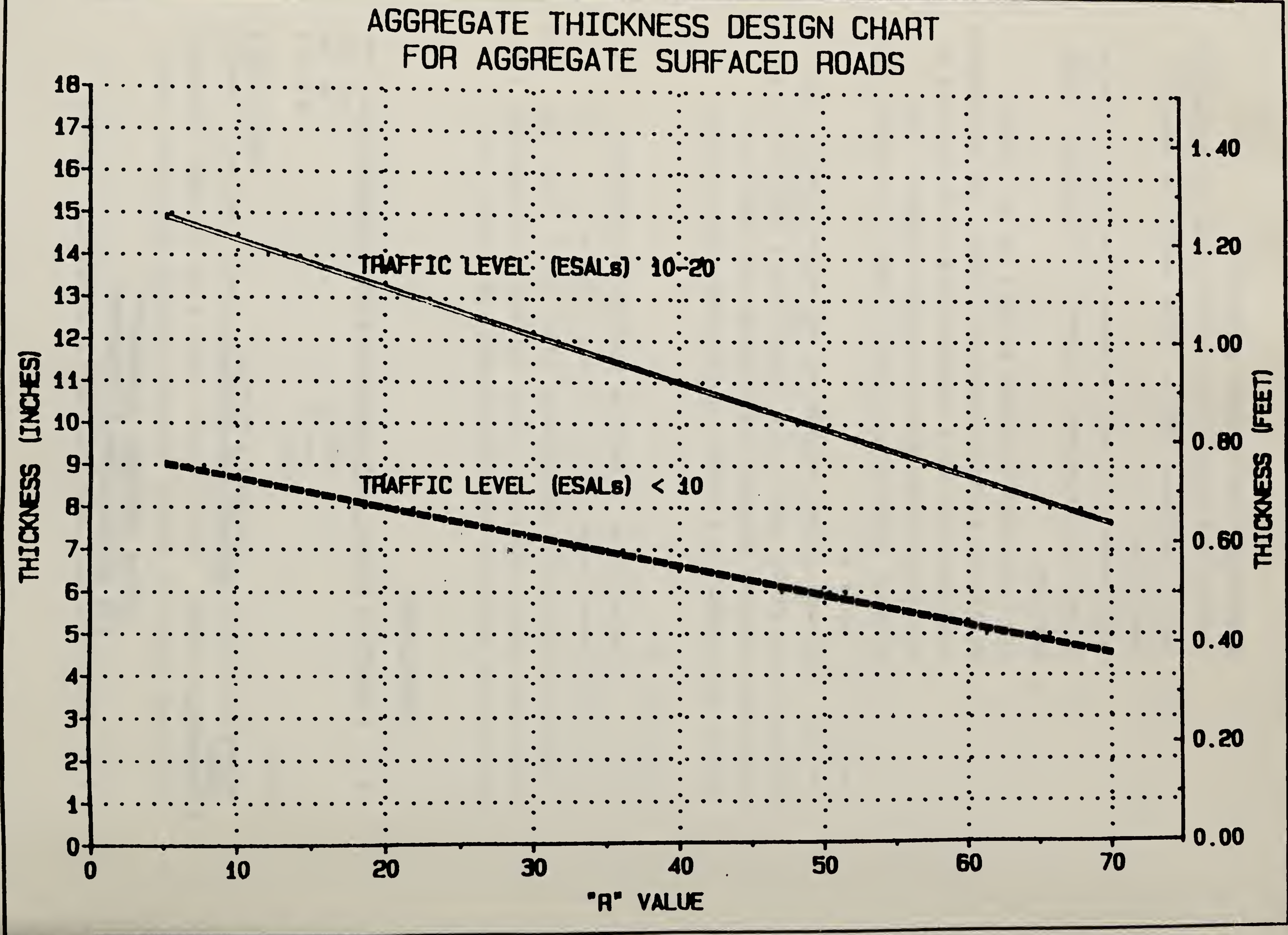
Double Bituminous Surface Treatment
- Aggregate first application - 30# of 3/4" per s.y.
- Aggregate second application - 25# of 1/2" per s.y.
- Bituminous material first application - 0.45 gal. per s.y.
- Bituminous material second application - 0.40 gal. per s.y.

Open Graded Plant Mix Seal
- Aggregate - 70# of 3/8" (open graded) per s.y.
- Asphalt Cement - (85-100 pen.) = 7% x weight of plant mix material
- Tack Coat - 0.05 gal. asphalt per s.y.

Plant Mix Seal Course
- Aggregate - 70# per s.y.
- Asphalt Cement - (85-100 pen.) = 7% x weight of plant mix material
- Tack Coat - 0.05 gal. asphalt per s.y.

These quantities will provide a nominal thickness of approximately 3/4". A 20% contingency should be added on jobs placed over an old roadway to allow for the uneven surface.

This estimating data is to be used unless specifically advised otherwise.



THICKNESS (INCHES)
THICKNESS (FEET)
TRAFFIC LEVEL (ESALs) 10-20
TRAFFIC LEVEL (ESALs) < 10
"R" VALUE

Table 3.4
AGGREGATE SPECIFICATION FOR AGGREGATE SURFACED ROADS

Sieve Size	Percentage Passing Nominal Maximum	Plasticity Index Range
3/4 in.	100	3-10
No. 4	40-80	
No. 10	25-60	
No. 200	5-20	

4.0 NEW AND RECONSTRUCTED PAVEMENTS (RIGID)

MDT uses the 1986 AASHTO pavement design guide for rigid pavement design. This section specifies the MDT procedure and inputs for determining rigid pavement and joint design.

4.1 DEVELOP EFFECTIVE MODULUS OF SUBGRADE REACTION

Before the design chart for determining design slab thickness can be applied, it is necessary to estimate the possible levels of slab support that can be provided. This is accomplished using Table 4.2 and Figures 4.3, 4.4., 4.5 and 4.6 to develop an effective modulus of subgrade reaction, k.

Since the effective k-value is dependent upon several different factors besides the roadbed soil resilient modulus, the first step is to identify the combinations (or levels) that are to be considered and enter them in the heading of Table 4.2.

(1) Subbase types -- different types of subbase have different strengths or modulus values. The consideration of a subbase type in estimating an effective k-value provides a basis for evaluating its cost-effectiveness as part of the design process.

(2) Subbase thicknesses (inches) -- potential design thicknesses for each subbase type should also be identified.

(3) Loss of support (LS) -- this factor is used to correct the effective k-value based on potential erosion of the subbase material.

For each combination of these factors that is to be evaluated, it is necessary to prepare a separate table and develop a corresponding effective modulus of subgrade reaction.

The second step of the process is to identify the seasonal roadbed soil resilient modulus values and enter them in Column 2 of each table.

The third step in estimating the effective k-value is to assign subbase elastic (resilient) modulus (E_{SB}) values for each season. These values should be entered in Column 3 of Table 4.2 and should correspond to those for the seasons used to develop the roadbed soil resilient modulus values. For those types of subbase material which are insensitive to season (e.g. cement-treated material), a constant value of subbase modulus may be assigned for each season. For those unbound materials which are sensitive to season but were not tested for extreme conditions, values for E_{SB} of 5,000 psi and 15,000 psi may be used for the frozen and spring thaw periods, respectively. For unbound materials, the ratio of the subbase to the roadbed soil resilient modulus should not exceed 4 to prevent an artificial condition.

The fourth step is to estimate the composite modulus of subgrade reaction for each season. If the slab is placed directly on the subgrade (i.e., no subbase), the composite modulus of subgrade reaction is defined using the following theoretical relationship between k-values from a plate bearing test and elastic modulus of the roadbed soil:

$$k = M_R/19.4$$

Note: The development of this relationship is described as part of Volume 2, Appendix HH of the 1986 AASHTO design guide.

Table 4.2: **Table for estimating effective modulus of subgrade reaction.**

Trail Subbase: Type ____________________

Thickness ____________________

Loss of Support, LS ________

Depth to Rigid Foundation (feet) __________

Projected Slab Thickness (inches) __________

MONTH	ROADBED MODULUS M_R (psi)	SUBBASE MODULUS E_{SB} (psi)	COMPOSITE k-VALUE (pci) (Fig. 3.5)	k-VALUE (pci) ON RIGID FOUNDATION (Fig. 3.4)	RELATIVE DAMAGE u_r (Fig. 3.5)
Jan.					
Feb.					
Mar.					
April					
May					
June					
July					
Aug.					
Sept.					
Oct.					
Nov.					
Dec.					

Summation: $\sum u_r$ = __________

Average: $\bar{u}_r = \frac{\sum u_r}{n} =$ __________

Effective Modulus of Subgrade Reaction, k (pci) = __________

Corrected for Loss of Support: k (pci) = __________

Example:

D_{SB} = 6 inches

E_{SB} = 20,000 psi

M_R = 7,000 psi

Solution: k_∞ = 400 pci

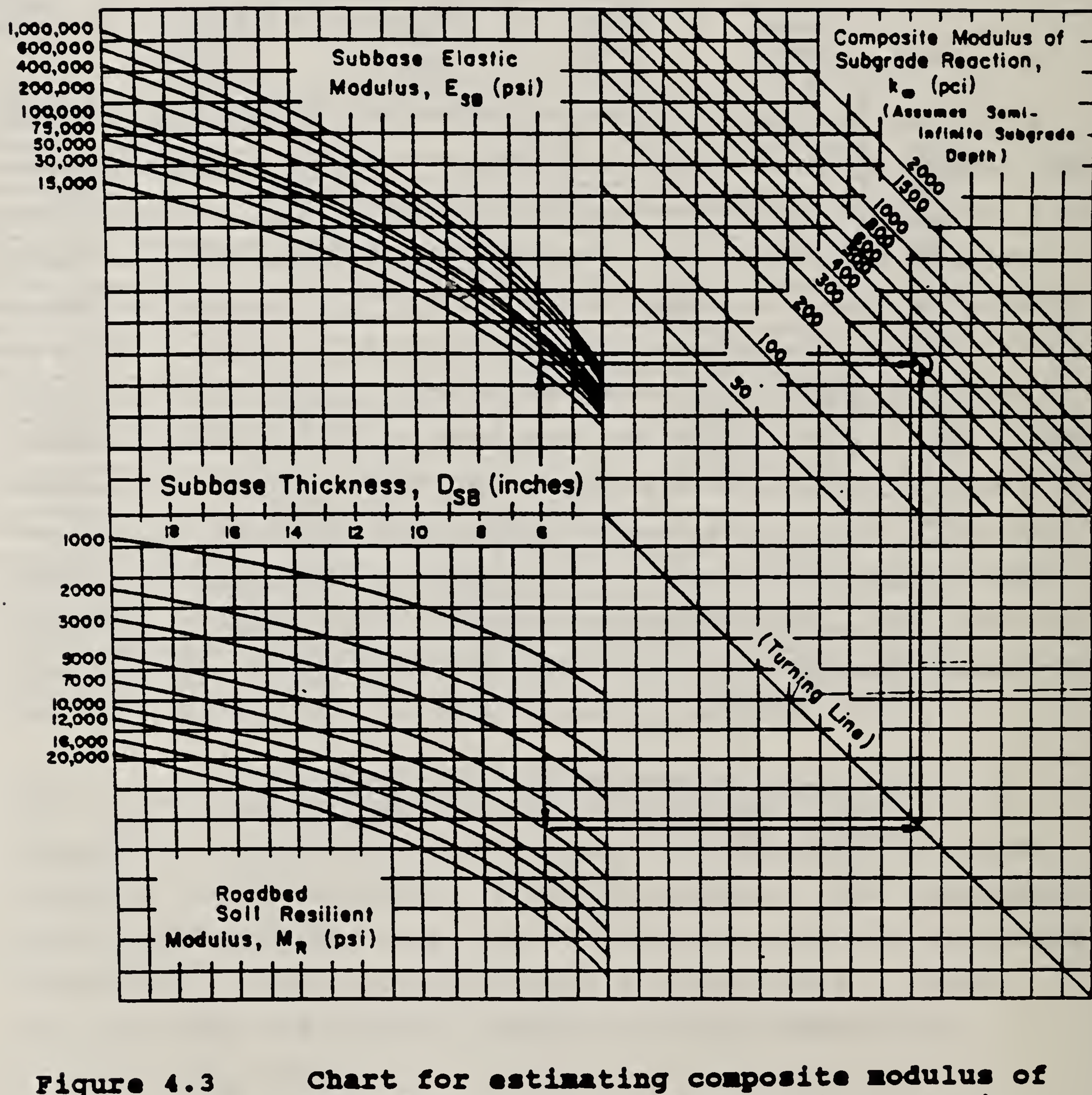


Figure 4.3 Chart for estimating composite modulus of subgrade reaction, k∞, assuming a semi-infinite subgrade depth. (For practical purposes, a semi-infinite depth is considered to be greater than 10 feet below the surface of the subgrade.)

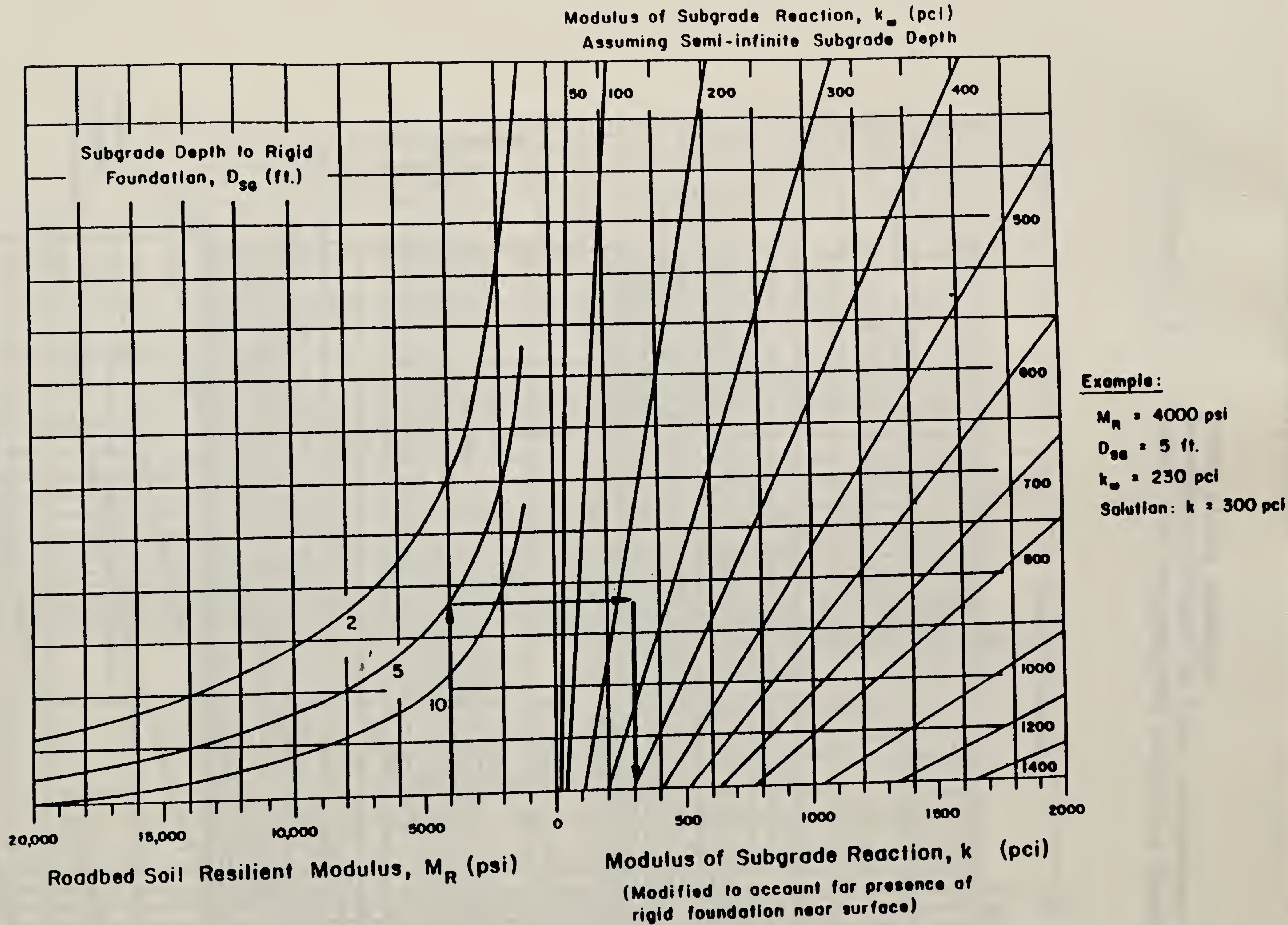


Figure 4.4 Chart to modify modulus of subgrade reaction to consider effects of rigid foundation near surface (within 10 feet).

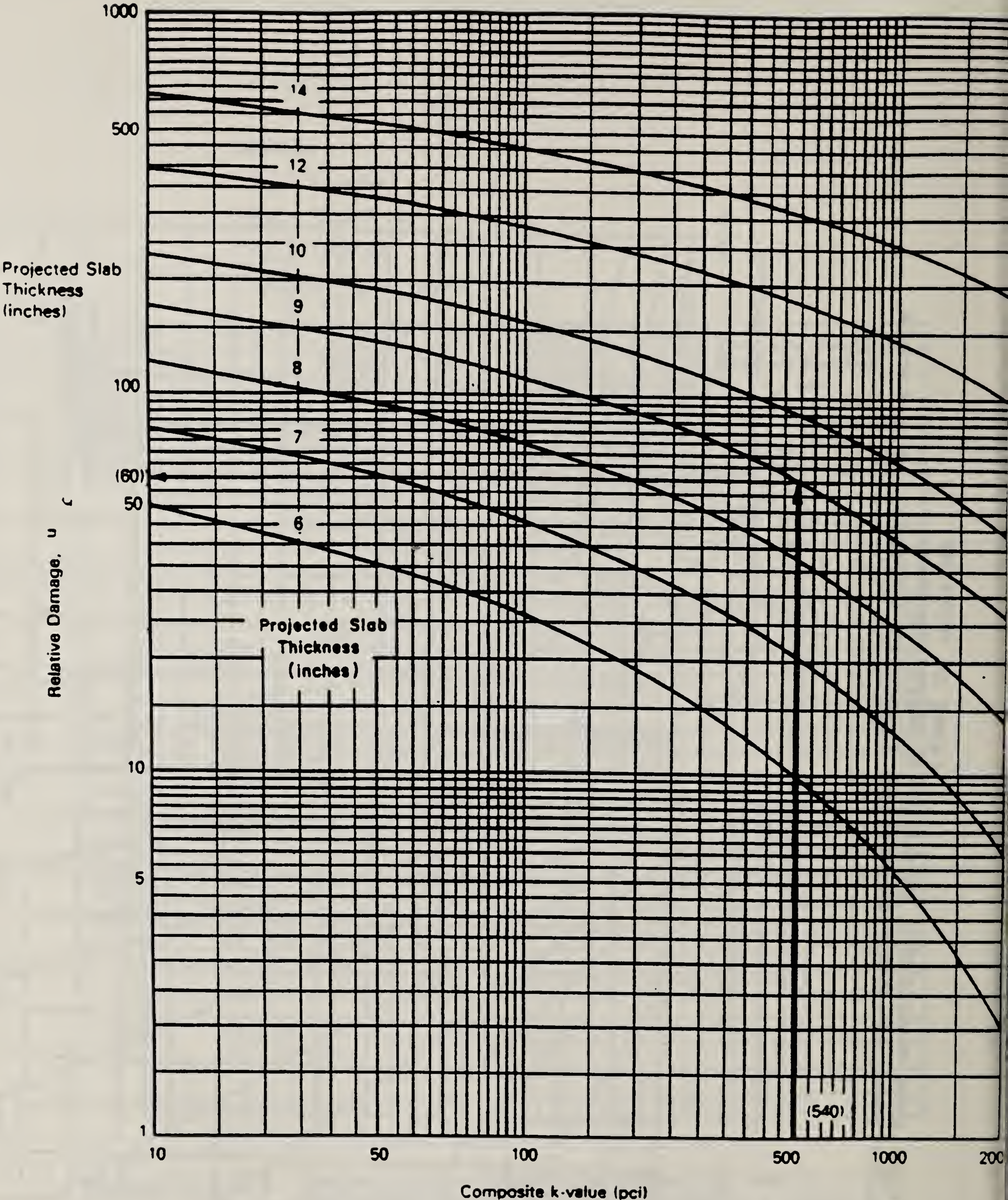


Figure 4.5 Chart for estimating relative damage to rigid pavements based on slab thickness and underlying support.

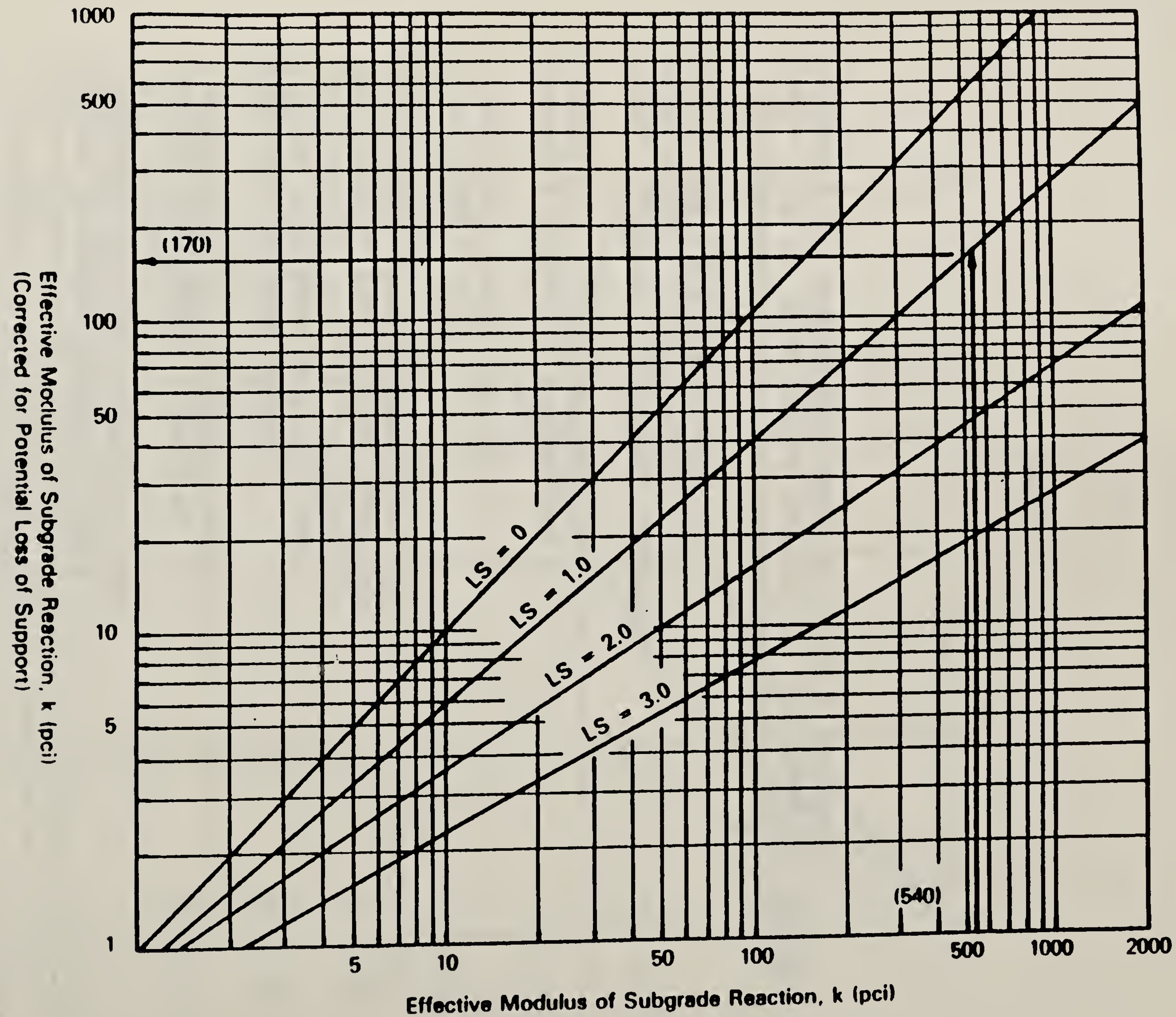


Figure 4.6 Correction of effective modulus of subgrade reaction for potential loss of subbase support (6).

Table 4.6: Typical ranges of loss of support (LS) factors for various types of materials (6).

Type of Material	Loss of Support (LS)
Cement Treated Granular Base (E=1,000,000 to 2,000,000 psi)	0.0 to 1.0
Cement Aggregate Mixtures (E=500,000 to 1,000,000 psi)	0.0 to 1.0
Asphalt Treated Base (E=350,000 to 1,000,000 psi)	0.0 to 1.0
Bituminous Stabilized Mixtures (E=40,000 to 300,000 psi)	0.0 to 1.0
Lime Stabilized (E=20,000 to 70,000 psi)	1.0 to 3.0
Unbound Granular Materials (E=15,000 to 45,000 psi)	1.0 to 3.0
Fine Grained or Natural Subgrade Materials (E=3,000 to 40,000 psi)	2.0 to 3.0

Note: E in this table refers to the general symbol for elastic or resilient modulus of the material.

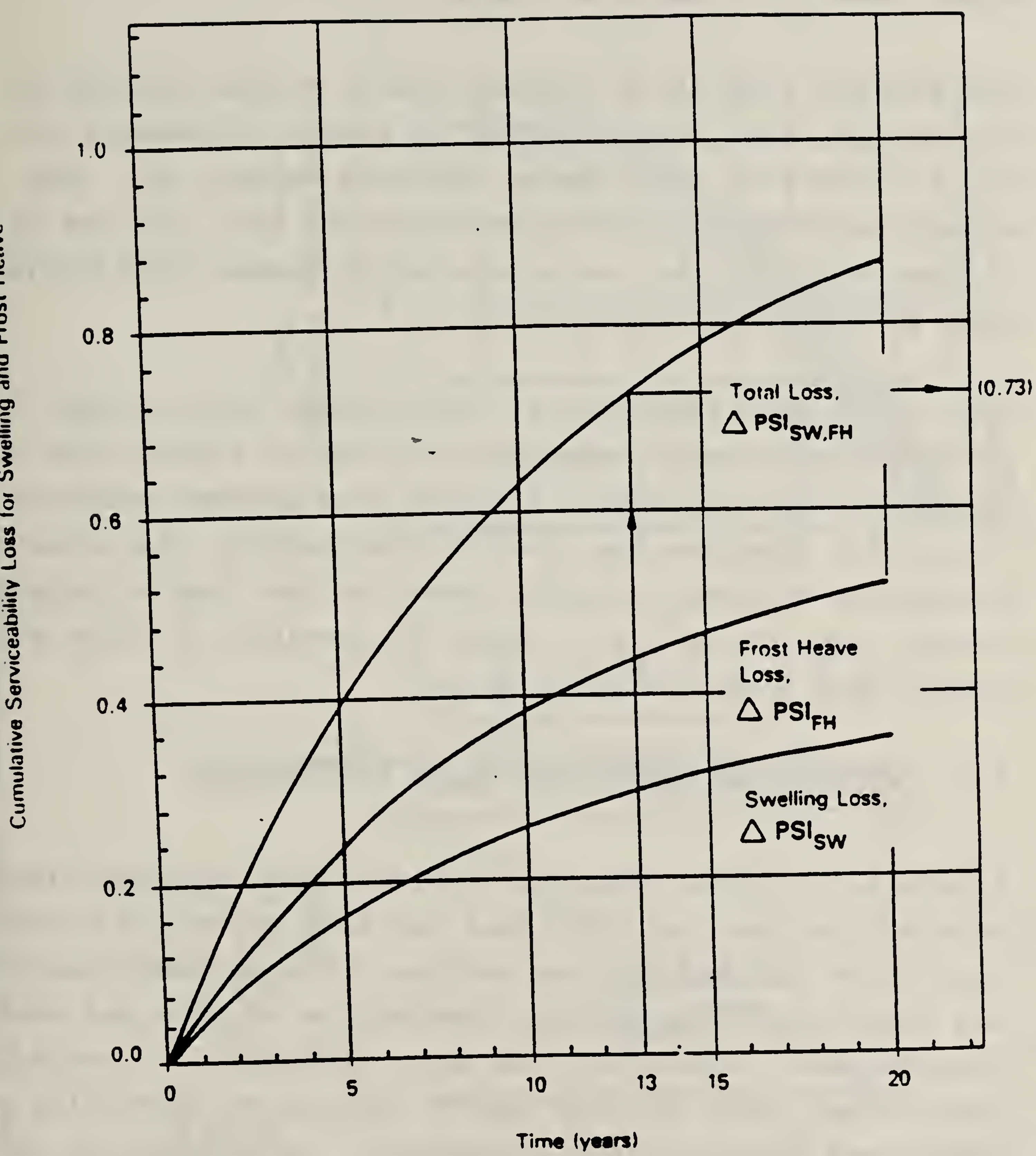


Figure 4.65 A conceptual example of the environmental serviceability loss versus time graph that may be developed for a specific location.

The sixth step in the process is to estimate the thickness of the slab that will be required, and then use Figure 4.5 to determine the relative damage, u_r, in each season and enter them in Column 6 of Table 4.2.

The seventh step is to add all the u_r values (Column 6) and divide the total by the number of season increments (12 or 24) to determine the average relative damage, u_r. The effective modulus of subgrade reaction, then, is the value corresponding to the average relative damage (and projected slab thickness) in Figure 4.5.

The eighth and final step in the process is to adjust the effective modulus of subgrade reaction to account for the potential loss of support arising from subbase erosion. Figure 4.6 provides the chart for correcting the effective modulus of subgrade reaction based on the loss of support factor, (see Table 4.6). Space is provided in Table 4.2 to record this final design k-value.

4.2 DETERMINE REQUIRED SLAB THICKNESS

Figure 4.7 (in two segments) presents the nomograph used for determining the slab thickness for each effective k-value identified in the previous section. The pavement designer may then select the optimum combination of slab and subbase thicknesses. Generally, the layer thickness is rounded to the nearest inch, but the use of controlled grade slip form pavers may permit ½-inch increments. In addition to the design k-value, other inputs required by this rigid pavement design nomograph include:

1) the estimated future traffic, W_{18} for the performance period,

2) the reliability, R

NOMOGRAPH SOLVES:

$$\log_{10} W_{18} = Z_R * S_o + 7.35 * \log_{10}(D+1) - 0.06 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.5 - 1.5}\right]}{1 + \frac{1.624*10^7}{(D+1)^{8.46}}} + (4.22 - 0.32 p_t) * \log_{10}\left[\frac{S'_c * C_d \left[D^{0.75} - 1.132\right]}{215.63 * J \left[D^{0.75} - \frac{18.42}{(E_c/k)^{0.25}}\right]}\right]$$

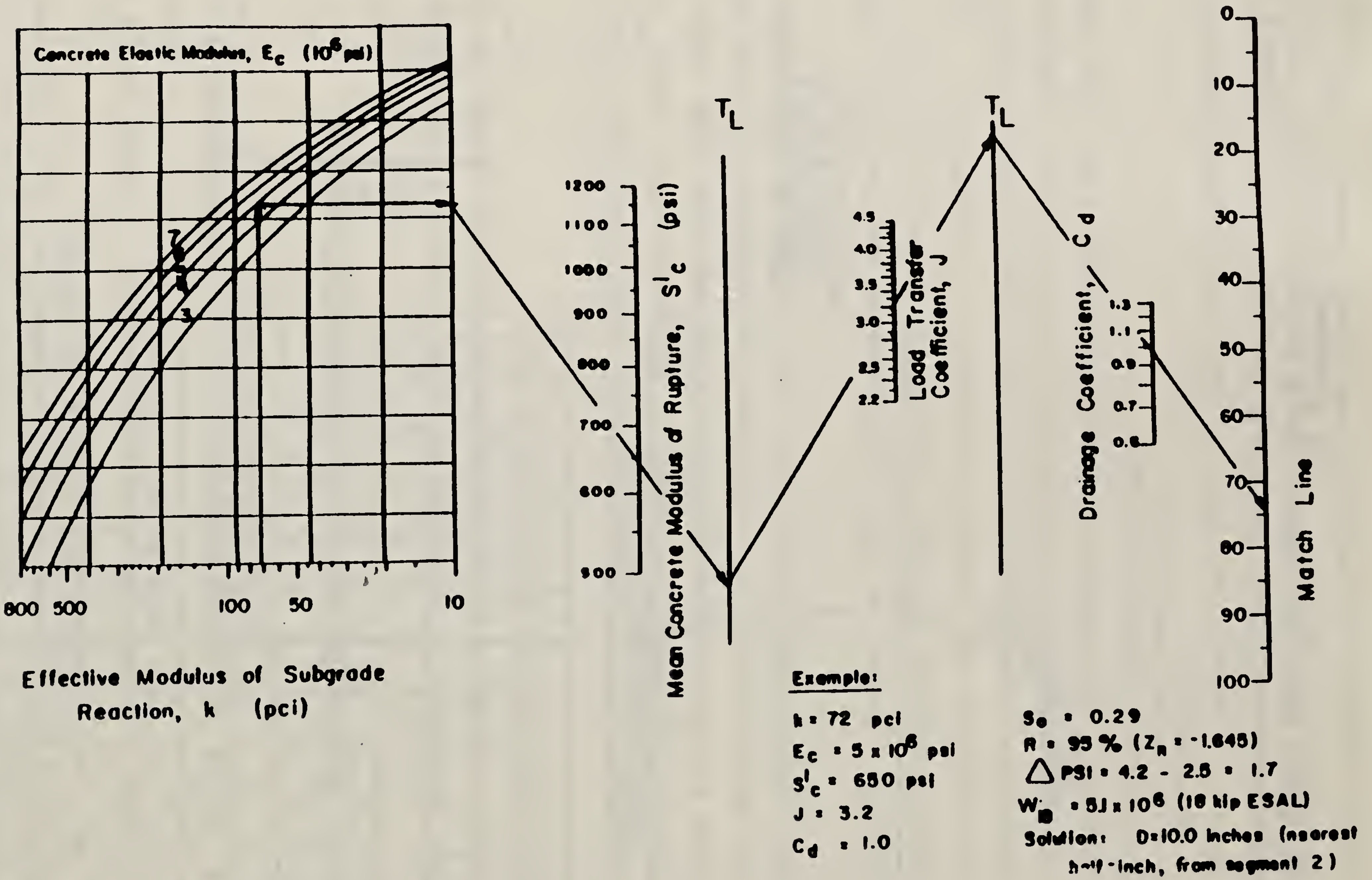


Figure 4.7 Design chart for rigid pavement based on using mean values for each input variable (Segment 1).

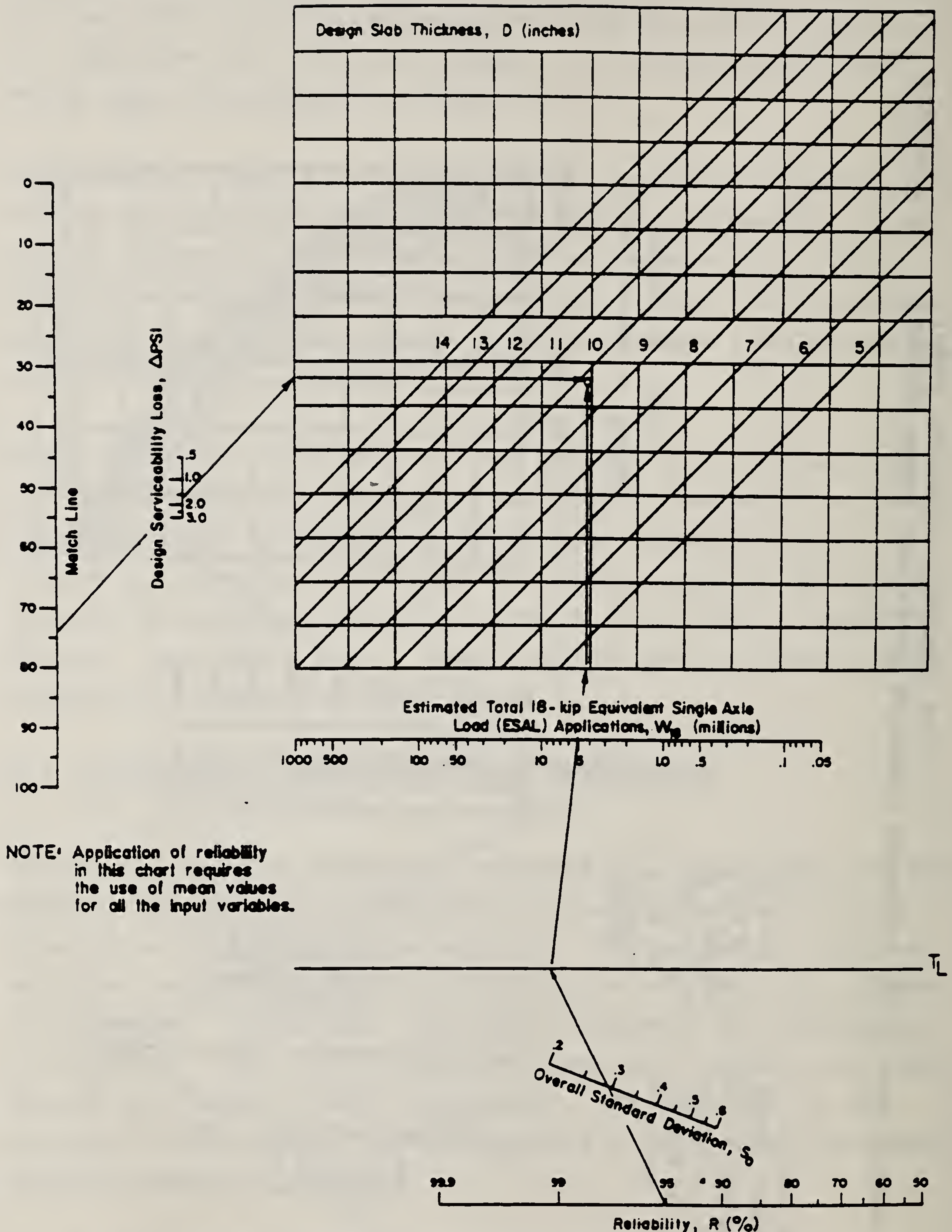


Figure 4.7 **Design chart for rigid pavements based on using mean values for each input variable (Segment 2).**

3) the overall standard deviation, S_o

4) design serviceability loss, $PSI = p_i - p_t$

5) concrete elastic modulus, E_c (5,000,000 psi will be used unless otherwise noted)

6) concrete modulus of rupture, S'_c (650 will be used unless otherwise noted)

7) load transfer coefficient, J (see Table 2.6 in the 1986 AASHTO Guide)

8) drainage coefficient, C_d (see Tables 2.4 or 2.5 in the 1986 AASHTO Guide)

4.3 ROADBED SWELLING AND FROST HEAVE

The approach to considering the effects of swelling and frost heave in rigid pavement design is almost identical to that for flexible pavements.

Step 1: Select an appropriate slab thickness for the initial pavement. Because of the relatively small effect slab thickness has on minimizing swelling and frost heave, the maximum initial thickness recommended is that derived for conditions assuming no swelling or frost heave.

Step 2: Select a trial performance period that might be expected under the swelling/frost heave conditions anticipated and enter in Column 2. (Table 4.2) This number should be less than the maximum possible performance period corresponding to the selected initial slab thickness. In general, the greater the environmental loss, the smaller the performance period will be.

Step 3: Using the graph of cumulative environmental serviceability loss versus time developed in Figure 4.2, estimate the corresponding total environmental serviceability loss due to swelling and frost heave ($PSI_{SW,FH}$) that

can be expected for the trial period from Step 2 and enter in Column 3. (Table 4.2)

Step 4: Subtract this environmental serviceability loss (Step 3) from the desired total serviceability loss to establish the corresponding traffic serviceability loss. Enter in Column 4.

$$PSI_{TR} = PSI - PSI_{SW,FH}$$

Step 5: Use Figure 4.7 to estimate the allowable cumulative 18-kip ESAL traffic corresponding to the traffic serviceability loss determined in Step 4 and enter in Column 5. Note that it is important to use the same levels of reliability, effective modulus of subgrade reaction, etc., when applying the rigid pavement design chart to estimate the allowable traffic.

Step 6: Estimate the corresponding year at which the cumulative 18-kip ESAL traffic (determined in Step 5) will be reached and enter in Column 6.

4.4 RIGID PAVEMENT JOINT DESIGN

This section covers the design considerations for the different types of joints in portland cement concrete pavements. This criteria is applicable to the design of joints in plain and jointed.

Joint Types

Joints are placed in concrete pavements to permit expansion and contraction of the pavement, thereby relieving stresses due to environmental changes (i.e., temperature and moisture), friction, and to facilitate construction. There are three general types of joints: contraction, expansion, and construction. These joints and their functions are as follows:

1) Contraction or weakened-plane (dummy) joints are provided to relieve the tensile stresses due to temperature, moisture, and friction, thereby controlling cracking. If contraction joints were not installed, random cracking would occur on the surface of the pavement.

2) The primary function of an expansion joint is to provide space for the expansion of the pavement, thereby preventing the development of compressive stresses, which can cause the pavement to buckle.

3) Construction joints are required to facilitate construction. The spacing between longitudinal joints is dictated by the width of the paving machine and by the pavement thickness.

Joint Geometry

The joint geometry is considered in terms of the spacing and general layout.

Joint Spacing. In general, the spacing of both transverse and longitudinal contraction joints depends on local conditions of materials and environmental, whereas expansion and construction joints are primarily dependent on layout and construction capabilities. The spacing is related to the slab thickness and the joint sealant capabilities. Local experience must be tempered since a change in coarse aggregate type may have a significant impact on the concrete thermal coefficient and consequently, the acceptable joint spacing. As a rough guide, the joint spacing (in feet) for plain concrete pavements should not greatly exceed twice the slab thickness (in inches). For example, the maximum joint spacing for an 8-inch slab is 16 feet. Also, as a general guideline, the ratio of slab width to length should not exceed 1.25.

The spacing between construction joints is generally dictated by field placement and equipment capabilities. Longitudinal construction joints should be placed at lane edges to maximize pavement smoothness and minimize load transfer problems. Transverse construction joints occur at the end of a day's placement or in connection with equipment breakdowns.

4.5 JOINT SEALANT DIMENSIONS

The joint sealant dimension guidelines are discussed for each joint type in the following sections.

Contraction Joints. Joint movement and the capabilities of the sealant material must be optimized. In general, the quality of the joint sealant material should increase as the expected joint movement increases. Increased joint movement can be the result of longer slab length, higher temperature change, and/or higher concrete thermal coefficient.

Joint movement in pavements is influenced by factors such as slab length volume change characteristics of the concrete, slab temperature range, and friction between the slab and subbase (or subgrade). Note that because of subgrade friction and end restraints, changes in joint width are less than what would be predicted by simple thermal contraction and expansion.

The joint width is defined as the maximum value that occurs at the minimum temperature. Thus, the maximum value includes the anticipated horizontal movement plus residual width due to sealant properties. The horizontal movement can be calculated by considering the seasonal openings and closings caused by temperature cycles plus concrete shrinkage. The amount of opening and closing depends on temperature and moisture change, spacing between working joints or cracks, friction between the slab and base, the

condition of the joint load transfer devices, etc. For design purposes, the mean transverse joint opening over a time interval can be computed approximately. The joint width must account for the movement plus the allowable residual strain in the joint sealant, and may be computed by the following:

$$L = \frac{Cl(\alpha_c \times DT_D + Z) \times 100}{S}$$

where

l = the joint opening caused by temperature changes and drying shrinkage of the PCC, in.,

S = allowable strain of joint sealant material. Most current sealants are designed to withstand strains of 25 to 35 percent, thus 25 percent may be used as a conservative value,

α_c - the thermal coefficient of contraction of portland cement concrete, °F (see Table 2.10 in 1986 AASHTO Guide),

Z - the drying shrinkage coefficient of the PCC slab, which can be neglected for a resealing project, in./in. (see Table 2.9 in 1986 AASHTO Guide),

L = joint spacing, in.,

DT_D - the temperature range, °F, (see Page II-31 in 1986 AASHTO Guide), and

C = the adjustment factor due to subbase/slab friction restraint. Use 0.65 for stabilized subbase, 0.80 for granular base.

For premolded sealants, the material and the movement must be optimized. The manufacturers generally publish aids for

selecting dimensions to suit the product. The sealant should be compressed between 20 and 50 percent of its nominal width. The sealant should be place 1/8 to 1/2 inch below the surface of the pavement.

5.0 FLEXIBLE PAVEMENT OVERLAY DESIGN

The MDT uses two different methods for overlay designs. Sections 5.0 - 5.3 will discuss the first method of the *Interim AASHTO Pavement Design Guide*. The second method will be discussed in Section 5.4 and is based on deflection analysis, utilizing Road Rater deflections.

5.1 INTERIM AASHTO DESIGN INPUTS

The MDT uses "R" values within the interim design guide. The exudation pressure used 300 pounds per square inch.

The following are the required inputs and information needed to perform the AASHTO overlay design.

1) Traffic data: As discussed in an earlier section, data is received from the Preconstruction Bureau. For specific questions, see Sections 3.1.

2) Determine design R-value from soils profile and laboratory test for the subgrade.

3) Determine the terminal serviceability index and the design period. The serviceability index used for interstates and primary is 2.5 and 2.0 for secondaries.

4) Determine the required structural number (SN), see earlier section 3.1 for a detailed explanation on how to calculate the required structural number. See the nomograph figure 3.4 for an exampled of how determine the required structural number.

5) Determine the existing structural number. This is done by multiplying the depth of each existing pavement

layer by its structural coefficient (Table 5.1) and reduction factor (Table 5.2) and then by adding the structural number of each layer. See the following table for an example.

PAVEMENT LAYER	LAYER THICKNESS		STRUCTURAL COEFFICIENT (ft.)	REDUCTION FACTOR		STRUCTURAL NUMBER
Plant Mix A.C. Grade B	0.40′	x	4.0	.7	=	1.12
Crushed Top Surfacing	0.20′	x	1.4		=	0.28
Crushed Gravel Base - 1½"	1.00′	x	1.4		=	1.40
	1.60′ TOTAL			TOTAL SN	=	2.80

6. Determine the overlay thickness, this is done by subtracting the existing structural number from the required structural number, divided by the structural coefficient for plant mix. See the following example:

Required SN	-	3.30	3.60
Existing SN	-	2.80	2.80
Needed SN	-	.50	.80 ÷ 4.0 = .20′
Overlay Thickness	-	$\frac{.5}{4.0}$ = .13′ overlay	

Note: The minimum thickness for PMBS overlays is 0.15′.

5.2 PAVEMENT OVERLAYS

A pavement overlay can be used if the pavement designer determines that an existing pavement is in reasonably good condition. As discussed in Section 2, a pavement overlay may be in conjunction with roadway widening and/or corrective work to the existing pavement. The depth of bituminous concrete overlay will be determined by the following procedure:

Pavement Overlay Design Work Sheet

The Pavement Design Worksheet is used to compute both new construction and overlay surfacing thickness. Unless otherwise noted, all designs are to be based on a 20-year design life. Information is provided by the following Data Sheets. (See pages 32-35.)

DATA SHEET 1:	**TRAFFIC - DAILY 18-KIP EQUIVALENT AXLE LOAD COMPUTATIONS**
DATA SHEET 2:	**DESIGN CALCULATION PROCEDURE FOR PMBS OVERLAYS**
DATA SHEETS 3 AND 4:	**DETERMINING STRUCTURAL NUMBER (SN)**

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TABLE 5-1

SURFACING COEFFICIENTS FOR STRUCTURAL COMPONENTS

SURFACING COURSES	R-Value 70> Per Inch	R-Value 60-70 Per Inch	R-Value 70> Per Foot	R-Value 60-70 Per Foot
Plant Mix Grade A	0.33	0.30	4.0	3.6
Plant Mix Grade B	0.33	0.30	4.0	3.6
Plant Mix Grade C	0.31	0.28	3.7	3.4
Road Mix	0.20	0.18	2.4	2.2
Milled Asphaltic Material	0.16	0.14	1.9	1.7
Crushed Gravel	0.12	0.10	1.4	1.2
TREATED BASE COURSES				
Bituminous Stabilized	0.20	0.18	2.4	2.2
Cement Treated +400 psi at 7 Days	0.20	0.18	2.4	2.2
Cement Treated -400 psi at 7 Days	0.15	0.14	1.8	1.7
Lime Treated	0.15	0.14	1.8	1.7
GRAVEL BASE COURSES				
Crushed Gravel 1½" Max.	0.12	0.10	1.4	1.2
Crushed Gravel over 1½"	0.11	0.09	1.3	1.1
Selected Surfacing	0.10	0.08	1.2	1.0
Special Borrow	0.07	0.06	0.8	0.7
Sand Surfacing	0.05	0.05	0.6	0.6

NOTE: The R-Values referred to in the headings are the general R-Values of surfacing sources found in the area of the project being designed.

TABLE 5-2

REDUCTION FACTORS FOR EXISTING PAVEMENT

Description of Existing Pavement[1]	Reduction Factor (RF)
Pavement surface exhibits appreciable cracking and crack patterns, little or no spalling along the cracks, some wheel path deformation, and essentially stable.	0.5-0.7
Pavement surface exhibits some fine cracking, small intermittent cracking patterns, and slight deformation in the wheel paths, and obviously stable.	0.7-0.9
Pavement surface generally uncracked, little or no deformation in the wheel paths, and stable.	0.9-1.0

1 This is based on a visual survey of the type and extent of distress. If the pavement distress and deterioration is worse than described in the table, consideration should be made for the removal and reconstruction of the pavement.

5.3 ELASTIC-LAYER OVERLAY EVALUATION AND DESIGN PROCEDURE FOR ASPHALT CONCRETE PAVEMENTS

1) DEFLECTION TESTING PROGRAM

MDT deflection analysis program utilizes a Road Rater. Presently, this system is used primarily to design and analyze overlay projects.

Deflection tests are taken at least every 880 feet. If deflections vary, additional tests will be taken to define weak or distressed areas. Besides the deflections, surface temperature and detailed roadway distress survey is conducted at each test location.

2) PROGRAM ANALYSIS INTRODUCTION

All three programs were developed by John Tennison of the New Mexico State Highway Department. They are used by the Road Rater Unit to process data collected in the field. A brief introduction for each of the three programs and their inputs are included herein.

For a full technical report, refer to "Proposed New Mexico State Highway Department Elastic-layer Overlay Evaluation and Design Procedure for Asphalt Concrete Pavements, Research Report MB-RR-83/2" prepared by the Materials Laboratory Bureau, New Mexico State Highway Department.

Several batch files and menu programs have been developed by the MDT to increase the overall efficiency of running these programs. All programs may be accessed by running the menu RDRMENU.

DRATER (ENG50118)

This program evaluates Road Rater deflection data to determine the respective resilient moduli of a given layer within a flexible pavement structure system. The basis for this program is the Chevron Research N-Layer Elastic Program for the calculations of stresses, strains, and deflections within a flexible pavement system.

This program back calculates elastic modulus for three layers. Printed output contains values for each layer as well as the means for each group of layers.

INPUT DATA

Enter the route number ________

For route number ____, enter the number of layers, including the subgrade, in the pavement structure (3 layers maximum): ________

Starting from the surface layer, enter the code for layer 1. The numerical codes are as follows:

1 = Asphalt cement concrete
2 = Asphalt cement-treated base
3 = Portland cement-treated base
4 = Untreated aggregate base
5 = Untreated aggregate subbase ________

Enter the average thickness (in inches) for layer 1: ________

Starting from the surface layer, enter the code for layer 2. See numerical codes above: ________

Enter the average thickness (in inches) for layer 2: ________

Enter the testing date (ex. May 28, 1983 would be entered as 052883) ________

Enter the beginning milepost: ________

Enter the ending milepost: ________

Enter the distance between tests (in feet): ________

Enter the load correction (in pounds): ________

Enter the mean 5-day air temperature (in degrees F) ________

Enter the number of tests between the beginning and ending milepost: ________

Deflection date (for each mile section): ________

Surface temperature (in degrees F for each mile): ________

DEFLECTION DATA FROM THE ROAD RATER (Example)

0	25.0	2410	2.22	1.71	1.05	.73	88.0	MP331 MAT88
1	25.0	2360	1.40	.97	.54	.36	88.0	
2	25.1	2410	1.40	.99	.55	.36	88.0	
3	25.0	2380	1.35	1.10	.75	.52	88.0	
4	24.9	2350	1.02	.71	.44	.32	88.0	
5	25.0	2370	4.66	3.69	2.13	1.16	88.0	
6	25.0	2390	3.47	2.62	1.42	.70	88.0	
7	24.9	2340	1.05	.74	.44	.30	88.0	
8	25.0	2510	5.32	3.92	1.94	.90	88.0	
9	25.0	2420	2.56	1.21	.56	.42	88.0	
0	25.0	2410	2.69	1.83	.97	.66	90.0	MP332 MAT90
1	25.0	2410	1.85	1.03	.48	.36	90.0	
2	25.0	2420	2.37	1.29	.61	.46	90.0	
3	25.0	2380	2.14	1.38	.62	.52	90.0	
4	25.0	2380	1.68	1.01	.55	.45	90.0	
5	25.0	2360	1.47	.88	.42	.35	90.0	
6	25.0	2390	1.81	.95	.48	.37	90.0	
7	25.0	2390	2.71	1.82	.91	.54	90.0	
8	25.0	2410	2.13	1.20	.58	.39	90.0	
9	25.0	2390	1.80	.85	.40	.32	90.0	
0	25.0	2310	1.12	.82	.47	.34	92.0	MP333 MAT92
1	25.0	2360	1.22	.59	.37	.31	92.0	
2	25.0	2360	2.10	1.17	.50	.34	92.0	
3	25.0	2380	1.57	1.51	.76	.54	92.0	
4	25.0	2350	.93	.61	.36	.30	92.0	
5	25.0	2380	1.91	1.11	.48	.33	92.0	
6	25.0	2360	1.89	1.05	.43	.28	92.0	
7	25.0	2340	1.25	.78	.45	.37	92.0	
8	25.0	2410	1.55	.89	.48	.37	92.0	
9	25.0	2400	1.03	.82	.58	.43	92.0	
10	25.0	2340	1.58	1.47	1.17	.93	0.0	MP334 MAT90

ESALs

The second program calculates the adjustment factor to the design ESALs value. This adjustment is based on the AASHTO flexible design equation, cumulative ESALs and road rater subgrade deflection analysis.

INPUT DATA

Enter the design terminal serviceability index (PT) for the existing pavement structure ________

Enter the design regional factor (R) for the existing pavement structure: ________

Enter the design structural number (SN) for the existing pavement structure: ________

Enter the design subgrade resilient modulus (in psi) from the road rater evaluation report: ________

Enter the base year for the existing pavement structure: ________

For the base year of the existing pavement structure, enter the ESALs (1) value: ________

Enter the base year for the proposed asphalt cement concrete overlay: ________

For the base year of the proposed asphalt cement concrete overlay, enter the ESALs (1) value: ________

Enter the unadjusted design ESALs for the proposed asphalt cement concrete overlay: ________

The third program determines the remaining serviceable life of a flexible pavement system using elastic layer theory and the results from the existing program "DRATER." To calculate design layer information, the number of layers is four with the first layer assumed to be the design layer. The program is based on the Asphalt Institute's DAMA program.

INPUT DATA

Enter the climatic station number for the center of the project: ________

Enter the design average daily loadings (ESALs): ________

Enter the design speed (mph): ________

Enter the Road Rater frequency (Hertz): ________

Enter the number of layers in the pavement structure (Maximum of 5 including the subgrade): ________

Starting from the top of the pavement structure, enter the material codes for each layer. The codes are as follows:

1 = asphalt cement concrete layer
2 = cement or lime aggregate treated layer
3 = untreated aggregate layer

Layer #	Code #
________	________
________	________
________	________

Is this asphalt cement concrete layer an already existing layer within the pavement structure (yes=1 and no=2):

Layer #	Yes or No	Mixture Default Values	% Aggregate Pass #200 Sieve	% Air Voids	Penetration @77°
________	___	________	________	______	________
________	___	________	________	______	________

Enter the thickness of the layers (in inches):

Layer #	Thickness

Enter the asphalt cement concrete modulus (in psi) from the road rater evaluation for each layer:

Layer #	ACC Modulus	
Subgrade		

LIFE OUTPUT (EXAMPLE)

```
The design speed (in mph) for the pavement
  structure is:                                             65.00
The road rater testing frequency (in Hertz) is:             25.00
Number of layers in the pavement structure is:                  4
Layer 1 is not an existing asphalt cement layer
The thickness of layer 1 (in inches) is                      3.95
Layer 2 is an existing asphalt cement layer
The asphalt cement concrete modulus (in PSI) for
  layer 2 is:                                             50000.0
The thickness of layer 3 (in inches) is:                    27.00
The aggregate base modulus (in PSI) for layer 3 is:       34900.0
The subgrade modulus (in PSI) is:                          7040.0

Processing using a temperature of 13.0 degrees F. for month
number 1
Processing using a temperature of 22.0 degrees F. for month
number 2
Processing using a temperature of 32.0 degrees F. for month
number 3
Processing using a temperature of 47.0 degrees F. for month
number 4
Processing using a temperature of 54.0 degrees F. for month
number 5
Processing using a temperature of 68.0 degrees F. for month
number 6
Processing using a temperature of 74.0 degrees F. for month
number 7
Processing using a temperature of 72.0 degrees F. for month
number 8
Processing using a temperature of 60.0 degrees F. for month
number 9
Processing using a temperature of 49.0 degrees F. for month
number 10
Processing using a temperature of 33.0 degrees F. for month
number 11
```

Processing using a temperature of 22.0 degrees F. for month number 12

*************** REMAINING ESTIMATED LIFE ***************

Layer	Damage Type	Cumulative Damage	Critical Position	Design Life(Years)	Design Repetitions
1	Fatigue	1.000	2	17.1	.1863E+09
2	Fatigue	1.000	3		.3891E+09
3	Rutting	1.000	3		.7917E+12

Layer 1 controls remaining life

The ESALs used to compute remaining life was 29894.
The reference climatic station number was 178.

combination of materials being more economical than a gravel base with asphalt surfacing. In cases where the districts or bureaus do not agree with the routine design, they may contact the Chairman of the Surfacing Selection Committee to resolve the differences. The Chairman will send copies of the final decision to all members of the Committee.

The Surfacing Selection Committee shall consist of the following members:

Supervisor of Pavement Analysis Section - Chairman
Administrator, Engineering Division
Construction Engineer
Preconstruction Engineer
Chief Maintenance Engineer
Materials Engineer
District Engineer - for jobs in their districts

STAGE CONSTRUCTION

In some cases, surfacing recommendations will show a future surfacing thickness. This is recommended only to insure the roadway width is designed to accommodate the future surfacing. No structural credit is given the future surfacing. The recommended surfacing overlay thickness will be for a 20-year design life. The 20-year design life will apply to all types of roadways.

FINAL DESIGN CHECK

The final check of the surfacing typical shall be made at the time of the preliminary plan-in-hand. This is Activity 610 in the Preconstruction Management System.

5.4 OVERLAY APPROVAL PROCESS

After both the AASHTO and deflection method of designs hav been conducted, both designs will be reviewed. If both designs agree, that design will be recommended. However, they disagree, both methods will be checked and/or additional tests taken. If they still differ, past performance and present pavement distress will be reviewed. The design recommendation will likely reflect the method that best indicates the past performance and distress.

Interstate project designs are to be submitted to the FHWA by the Materials Engineer for their approval.

After the flexible section has been determined, if it is n obvious it is the most satisfactory choice, prepare alternate designs and cost estimates.

The Surfacing Selection Committee will consider all major projects where alternative materials or procedures such as concrete or cold recycling will provide similar economics and additional benefits. Also, alternative design lives (8 year etc.) will be considered. In addition, overlay projects with an overlay greater than 0.30′ for a ten-year design and greater than 0.40′ for a twenty-year design, to determine a feasible alternative. The Administrator of the Engineering Division will review the committee's decision and approve or disapprove it. Results of the decision wil be distributed to all members.

The Surfacing Selection Committee will not consider routin surfacing designs where there is little chance of any combination of materials being more economical than a grav base with asphalt surfacing. In cases where the districts or bureaus do not agree with the routine design, they may contact the Chairman of the Surfacing Selection Committee t

resolve the differences. The Chairman will send copies of the final decision to all members of the Committee.

The Surfacing Selection Committee shall consist of the following members:

Supervisor of Pavement Analysis Section - Chairman
Administrator, Engineering Division
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Preconstruction Engineer
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STAGE CONSTRUCTION

In some cases, surfacing recommendations will show a future surfacing thickness. This is recommended only to insure the roadway width is designed to accommodate the future surfacing. No structural credit is given the future surfacing. The recommended surfacing overlay thickness will be for a 20-year design life. The 20-year design life will apply to all types of roadways.

FINAL DESIGN CHECK

The final check of the surfacing typical shall be made at the time of the preliminary plan-in-hand. This is Activity 610 in the Preconstruction Management System.

6.0 SURFACE TREATMENT

Open-graded friction course as a surface treatment is no longer being recommended. Plant mix seals may be recommended; however, the plant mix course it will cover must be reviewed and analyzed for moisture and stripping susceptibility. Final approval for using a plant mix seal must come from the Highway Division Administrator.

Seal and covers will be recommended on all interstate, primary, and secondary projects. Urban projects will not receive surface treatments unless otherwise approved. Cov aggregates shall generally be 3/8" gradation.

7.0 ECONOMIC EVALUATION OF ALTERNATIVE PAVEMENT DESIGN STRATEGIES

7.1 INTRODUCTION

The application of principles of engineering economy to pavement projects occurs generally at two levels. First, there are the management decisions required to determine t feasibility and programming of a project; second, there is the requirement to achieve the maximum economy within that project if the project is economically feasible as a whole

The major difference in economic evaluation between these two levels of pavement management concerns the amount of detail and information required. Otherwise, the basic principles involved are the same. This section considers both these principles and their incorporation into methods of economic evaluation. Such models then become a vital part of the pavement design process.

It is essential in economic evaluation that all costs occurring during the life of the facility be included. When making economic comparisons this has not always been carefully practiced or even understood by pavement designers because comparisons were often made over a fixed, equal design period. Thus, designers assumed that first-cost comparisons were adequate for economic studies. This is not true, and, in order to emphasize the need for a complete cost analysis, the term "life-cycle costs" was coined.

Life-cycle costs refer to all costs (and, in the complete sense, all benefits) which are involved in the provision of a pavement during its complete life cycle. These include, of course, construction costs, maintenance costs, rehabilitation costs, etc.

7.2 DEFINITIONS RELATED TO ECONOMIC ANALYSIS

The following are groups of definitions used in Economic Analysis.

Highway Maintenance Cost - the cost of keeping a highway and its appurtenances in serviceable condition. Changes in administrative costs that can be allocated to a particular improvement should also be included.

Highway User Costs - the sum of (1) motor vehicle running cost, (2) the value of vehicle user travel time, and (3) traffic accident cost.

Incremental Cost - the net change in dollar costs directly attributable to a given decision or proposal compared with some other alternative (which could be the existing situation, or the "do-nothing" alternative).

Present Value (PV) - an economic concept that represents th translation of specified amounts of costs or benefits occurring in different time periods into a single amount at a single instant (usually the present). Another name for present value is "present worth." The tern "net present value" (NPV) refers to the net cumulative present value of series of costs and benefits stretching over time. It is derived by applying to each cost or benefit in the series a appropriate discount factor, which converts each cost or benefit to a present value. Two related considerations underlie the need for computing present values: (1) the fact that money has an intrinsic capacity to earn interest over time (known as the time value of money) due to its productiveness and scarcity, and (2) the need in an economi study for comparing or summing incremental outlays or savings of money in different time periods.

Equivalent Uniform Annual Cost (or Benefit) - a uniform annual cost (or benefit) that is the equivalent, spread ove the entire period of analysis, of all incremental disbursements or costs incurred on (or benefits received from) a project. Equivalent annual cost (or benefit) is an obverse form of present value. That is, the present value of the uniform series of equivalent annual cost equals the present value of all project disbursements.

Analysis Period - the length of time (usually the number of years) chosen for consideration and study of incremental benefits and costs in an economic analysis.

Residual or Salvage Value - the value of an investment or capital outlay remaining at the end of the study or analysi period.

Project - any relatively independent component of a propose highway improvement.

Project Alternatives - any variations to a basic project plan that (1) entail significantly different costs, (2) result in significantly different levels of service or demand, or (3) incorporate different route locations or other distinctive design feature such as surfacing type.

Initial Costs (Investment Costs) - computing the initial cost of construction involves the calculation of material quantities to be provided in each pavement structure and multiplication by their unit prices. Material quantities are generally direct functions of their thicknesses in the structure. They are also functions of thicknesses of other layers and the width of pavement and shoulders.

Inflation Rate - MDT will use an inflation rate of 4 percent.

Rehabilitation and Resurfacing Cost - rehabilitation costs include future overlays and/or upgrading made necessary when the riding quality of a pavement decreases to a certain minimum level of acceptability, for example, a present serviceability index (PSI) of 2.5. For purposes of this report, resurfacing costs are included in the rehabilitation category.

Pavement Rehabilitation - work undertaken to extend the service life of an existing facility. This includes placement of additional surfacing material and/or other work necessary to return an existing roadway, including shoulders, to a condition of structural or functional adequacy. This could include the partial removal and replacement of the pavement structure.

Pavement rehabilitation work shall not include normal periodic maintenance activities. Periodic maintenance is interpreted to include such items as resurfacing less than

K-inch in thickness or of short length; patching, filling potholes, sealing cracks and joints or repair of minor failures, and undersealing of concrete slabs other than as an essential part of rehabilitation; and other work intende primarily for preservation of the existing roadway.

Pavement rehabilitation projects should substantially increase the service life of a significant length of roadway. The following are a few examples of possible pavement rehabilitation work appropriate for major highway projects:

(1) resurfacing to provide improved structural capacity or serviceability (including in some cases cracking and seating);

(2) replacing or restoring malfunctioning joints;

(3) substantial pavement undersealing when essential for stabilization;

(4) grinding or grooving of pavements to restore smoothness or skid resistance, providing adequate structural thickness remains;

(5) removing and replacing deteriorated materials;

(6) reworking or strengthening of bases or subbases;

(7) recycling of existing materials;

(8) cracking and seating of PCC pavements with AC overlays; and

(9) adding underdrains.

This list is not all-inclusive. There are other items that could be added which satisfy the above definition. However, it is imperative that the definition be applied consistently nationwide.

The common practice of selecting a rehabilitation technique only because it has the lowest initial construction cost is a poor engineering practice and can lead to serious future pavement problems. The consideration of life-cycle costs is recommended in selecting the preferred alternative. The various costs of the pavement rehabilitation alternatives are the major consideration in selecting the preferred alternative. Life-cycle costs include (1) costs to the highway agency of initial design and construction, future maintenance and rehabilitation, and salvage value; and (2) costs to the highway user including travel delays from lane closures and rough pavements, vehicle operation, accidents and discomforts.

7.3 FACTORS INVOLVED IN PAVEMENT COSTS AND BENEFITS

The major initial and recurring costs that should be considered in the economic evaluation of alternative pavement strategies include the following:

(1) Agency costs

- a) initial construction costs
- b) future construction or rehabilitation costs (overlays, seal coats, reconstruction, etc.)
- c) maintenance costs, recurring throughout the design period
- d) salvage return or residual value at the end of the design period (which may be a "negative cost")

e) engineering and administration costs
f) traffic control costs if any are involved

(2) User costs

a) travel time
b) vehicle operation
c) accidents
d) discomfort
e) time delay and extra vehicle operating costs during resurfacing or major maintenance

7.4 METHODS OF ECONOMIC EVALUATION

There are a number of methods of economic analysis that are applicable to the evaluation of alternative pavement design strategies.

(1) Equivalent uniform annual cost method, often simply termed the "annual cost method"

(2) Present worth method for:

a) costs
b) benefits, or
c) benefits minus costs, usually termed the "net present worth" or "net present value method"

(3) Rate-of-return method

(4) Benefit-cost ratio method

(5) Cost-effectiveness method

EQUATIONS FOR ECONOMIC ANALYSIS

For this section, only the annual cost and present worth methods of analysis are presented because of their wide applicability and acceptance.

Equivalent Uniform Annual Cost Method

The equivalent uniform annual cost method combines all initial capital costs and all recurring future expenses into equal annual payments over the analysis period. In equation form, this method may be expressed as:

$$AC = crf\ (ICC) + (AAMO) + (AAUC) - crf\ (SV)$$

where

AC = equivalent uniform annual cost for alternative x_1, for a service life or analysis period of n years,

cfr = capital recovery factor for interest rate i and n years,
= $i(1 + i)^n / (1 + i)^n - 1$

(ICC) = initial capital costs of construction (including actual construction costs, materials costs, engineering costs, etc.),

(AAMO) = average annual maintenance plus operation costs for alternative x_1,

(AAUC) = average annual user costs for alternative x_1 (including vehicle operation, travel time, accidents, and discomfort if designated), and

(SV) = salvage value, if any, for alternative x_1 at the end of n years.

The above equation considers annual maintenance and operating costs, and user costs, on an average basis. Thi[s] can be satisfactory for many purposes. Where such costs d[o] not increase uniformly.

Present Worth Method

The present worth of costs method is directly comparable t[o] the equivalent uniform annual cost method for comparable conditions, e.g., costs, discount rates, and analysis periods. The present worth method can consider either cos[ts] alone, benefits alone, or costs and benefits together. It involves bringing all future sums to the present, using an appropriate inflation rate. The factor (5) for discountin[g] either costs or benefits is:

pwf = present worth factor for a particular i and n,

i = inflation rate, and

n = number of years to when the sum will be expended or saved.

Published tables for pwf, or the cst, are readily availabl[e] in a wide variety of references.

The present worth method for costs alone can be expressed terms of the following equation (5):

$$TWPC = (ICC) + \sum_{t=0}^{t=1} pwf\ [(CC) + (MO) + (UC)] - (SV)\ pwf$$

where

TWPC = total present worth of costs for alternative x_1, for an analysis period of n years,

(ICC) = initial capital costs of construction, etc., for alternative x_1,

(C) = capital costs of construction, etc., for alternative x_1, in year t, where t is less than n,

pwf = present worth factor for inflation rate, i, for t years,
= $1/(1 + i)^t$,

(MO) = maintenance plus operation costs for alternative x_1 in year t,

(UC) = user costs (including vehicle operation, travel time, accidents, and discomfort if designated) for alternative x_1, in year t, and

$(SV)_{x1,n}$ salvage value, if any, for alternative x_1, at the end of the design period, n years.

Although the present worth of costs method is directly comparable to the equivalent uniform annual cost method, it is only in recent years that it has begun to be applied to the pavement field.

The present worth of costs is used in the equivalent uniform annual cost method when additional capital expenditures occur before the end of the analysis period, i.e., when the service life is less than the analysis period; and future rehabilitation, such as overlays or seal coats, is needed.

$$AC = crf\ [(ICC) + R_1pwf = R_2pwf + \ldots + R_jpwf + (AAMO) + (AAUC) - crf\ (SV)]$$

where

AC	=	equivalent uniform annual cost for alternative x_1, for an analysis period of n years,
$R_1, R_2, \ldots, R_j$	=	costs of first, second, ..., j^{th} resurfacings, respectively, and
$a_1, a_2, \ldots, a_j$	=	ages of first, second, ..., j^{th} resurfacings occur respectively.

All factors are as previously defined.